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FINAL REPORT

INTERMEDIATE WATER RECOVERY SYSTEM

CONTRACT NAS 9-11996

72-8901, Rev. 1 12 April 1973

AIRESEARCH MANUFACTURING COMPANY

A DIVISION OF THE GARRETT CORPORATION

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Los Angeles, California

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INTRODUCTION AND SUMMARY

GENERAL

The Intermediate Water Recovery System (IWRS) is intended to be used for the collection, storage, and processing of urine, wash water, and humidity condensate from a crew of three aboard a spacecraft. Potable product water extracted from these three waste-water sources can be stored in the IWRS tanks or returned directly to the spacecraft water supply. The IWRS is automatically operated and is instrumented for continuous monitoring.

BACKGROUND

Background information pertaining to previous phases of the IWRS development program is briefly summarized below.

Design and development of the IWRS was initially conducted as an Independent Research and Development program beginning in 1967. The pilot plant built and tested under this program demonstrated that high-quality, bacteria-free water can be produced by a flash-evaporation, vapor-compression, vapor-pyrolysis process and that at least 95-percent water recovery can be attained.

The program was continued under Task A of NASA Contract NAS 9-8460, which led to the development of hardware approaches for the phase separator and heater-condenser and the selection of system control techniques. The Task A phase of the development program was followed by a preliminary design of the entire IWRS under Task B of the same contract. Concurrently, further development of components for, and testing of, the waste water processing portion of the IWRS was carried out under NASA Contract NAS 9-9981. Tests performed on the upgraded breadboard system in this phase of the program demonstrated the capability of the processing system to produce high-quality water from urine using the hardware approaches and semi-batch fluid inventory control methods that had been developed. The breadboard system tests were useful in providing a clearer understanding of system operational peculiarities and in identifying further component design requirements.

It was apparent from problems encountered during system testing that some breadboard system components required further development to allow system-level testing to be performed for longer periods without breakdown and to improve system efficiency. AiResearch recommendations for component improvements and further areas of investigation led to the program phase covered in this report.

SCOPE OF CURRENT PROGRAM

The current program for development of a breadboard water recovery system is an extension of work conducted under NASA Contracts NAS 9-8460 and NAS 9-9981. The scope of the work concerns redesigning the phase separator, modifying the vapor compressor and control system, integrating these components into an improved breadboard system, and performing a long-term test on the system using automatic controls and logic circuitry for unattended operation and automatic shutdown in case of a malfunction.

Initial plans were to perform a 120-day breadboard water recovery system test with urine. This test, started on 25 April 1972, was aborted on 10 June after 340.5 hr of operation during which the system was shut down several times, either manually or automatically, because of various problems with the phase separator and pyrolysis reactor then in use. The breadboard system was refurbished in an attempt to correct the problems encountered in the aborted test. With the modifications made and the plumbing simplified, the refurbished IWRS was operated without total system shutdown for a 30-day test period with urine (starting on 21 October and ending on 20 November 1972).

SUMMARY OF TEST RESULTS

The system produced clear, sterile water during the entire test period. Results of the 30-day test showed that 350 lb of product water was recovered from the 363 lb of water available in the 380 lb of urine processed during the test. The percent of product water recovered from the water available in the urine was 96.4. Ammonia content in the product water was within acceptable limits for the first 20 days of the system operation, but was excessive during the remaining 10 days. Some minor hardware problems that occurred were corrected by shutting down only the affected part of the system.

SECTION 2

COMPONENT DEVELOPMENT AND MODIFICATIONS

GENERAL

The major activity performed in upgrading the previous breadboard IWRS for the 120-day test was the design and development of an entirely new phase separator. The new separator, although basically similar in design to the unit previously tested, contained several important improvements intended to minimize or eliminate past deficiencies: Oval tubes and splash plates were used to minimize the plume effect of the pitot brine pickup; the inner bowl configuration was changed to improve brine pickup and level sensing characteristics; most important, a magnetic coupling was incorporated between the drive motor and the inner bowl to eliminate the air leakage problem inherent in the previous rotary seal.

Fluid inventory control for the semi-batch water recovery process was simplified and refined so that the IWRS could be operated more efficiently. The bearings of the existing compressor and its motor were replaced with precision bearings and preloaded to increase operating life. Because of the long-term testing planned for the current program, automatic shutdown sequence logic circuitry were developed for the system. An automatic shutdown sequence was incorporated to reduce the need for failure monitoring by test personnel. For the 30-day test, the system was modified so that the automatic shutdown sequence would be initiated only if brine loop pressure, sensed by a pressure switch located downstream of the heater-condenser at P_2, was too low.

PHASE SEPARATOR MODIFICATIONS

Background

The preceding breadboard separator tests established that the basic design approach, using the rotating bowl and pitot brine pickup, was sound, but that further development was necessary to reduce liquid entrainment, eliminate sealing problems, and reduce mechanical and frictional power losses.

Scope of Current Program

As a result of the operating difficulties encountered in the previous program, it was decided to completely redesign the phase separator. Figure 2-1 shows a cross section of the new unit. Figures 2-2 and 2-3B show the separator components prior to assembly. Improved features incorporated in the new unit are described below:

(a) The carbon seal was replaced with a magnetic coupling between the drive motor and the rotating bowl, thus preventing air leakage into the separator and reducing motor power usage.

(b) The bowl diameter was increased to linearize the response of the necleonic level sensing device. Also, with the total capacity of the separator increased, the unit could operate at a lower brine density during most of the cycle. Liquid levels are shown on Figure 2-4.

(c) The inlet line diameter was increased and an integral flow swirler was added to reduce the spray produced by the high-velocity addition of flashing urine and to partially separate the steam from the urine. The slower moving swirling flow was directed against the conical rotating end wall of the separator. Steam passing through the rotating conical diffusion demistor reduced the liquid carry-over from the bowl into the vapor loop. Vapor condensation was reduced by wrapping a flexible strip heater around the outside separator shell to keep its temperature above the saturation point.

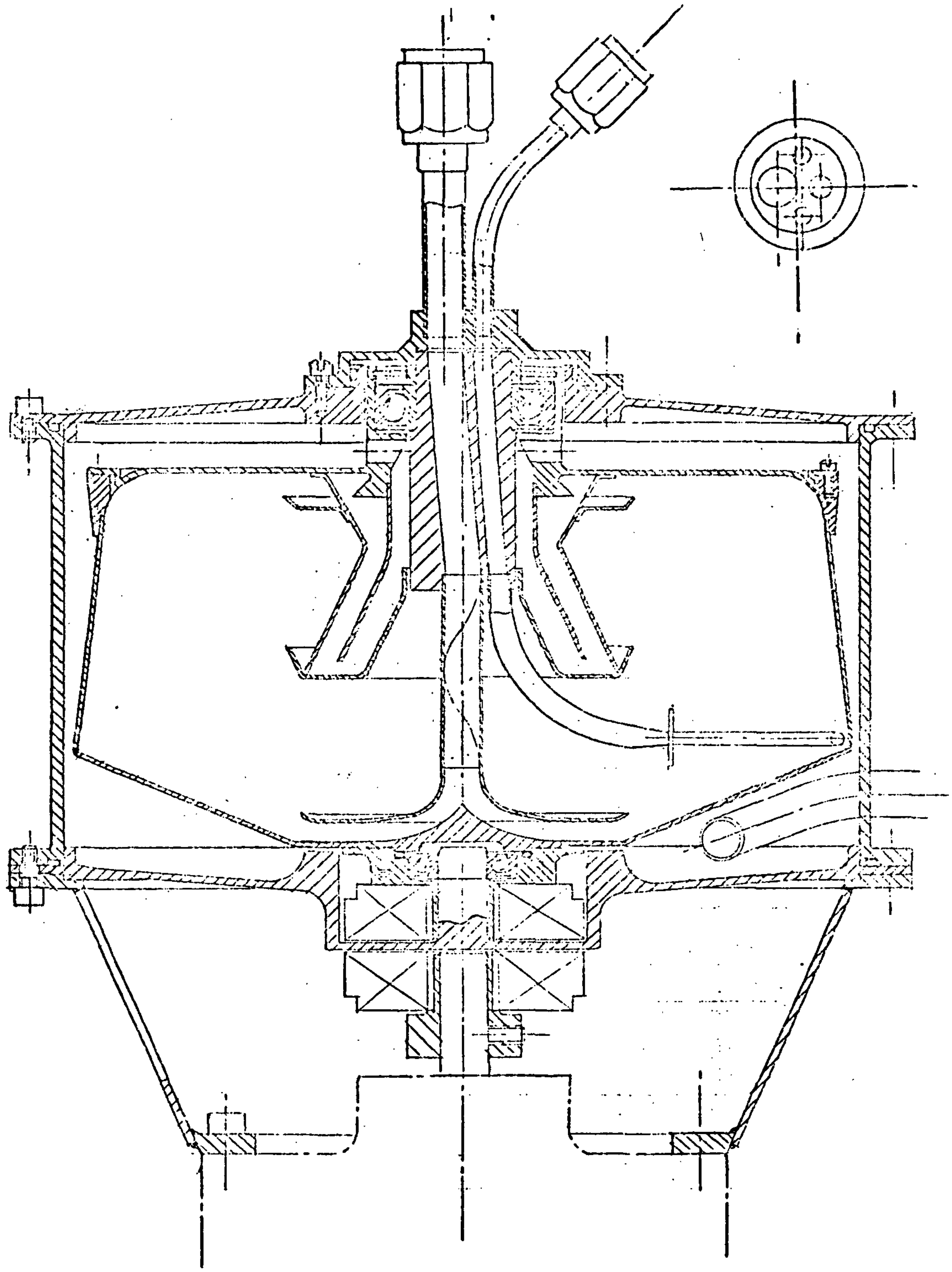


Figure 2-1. Phase Separator Cross-Sectional Diagram

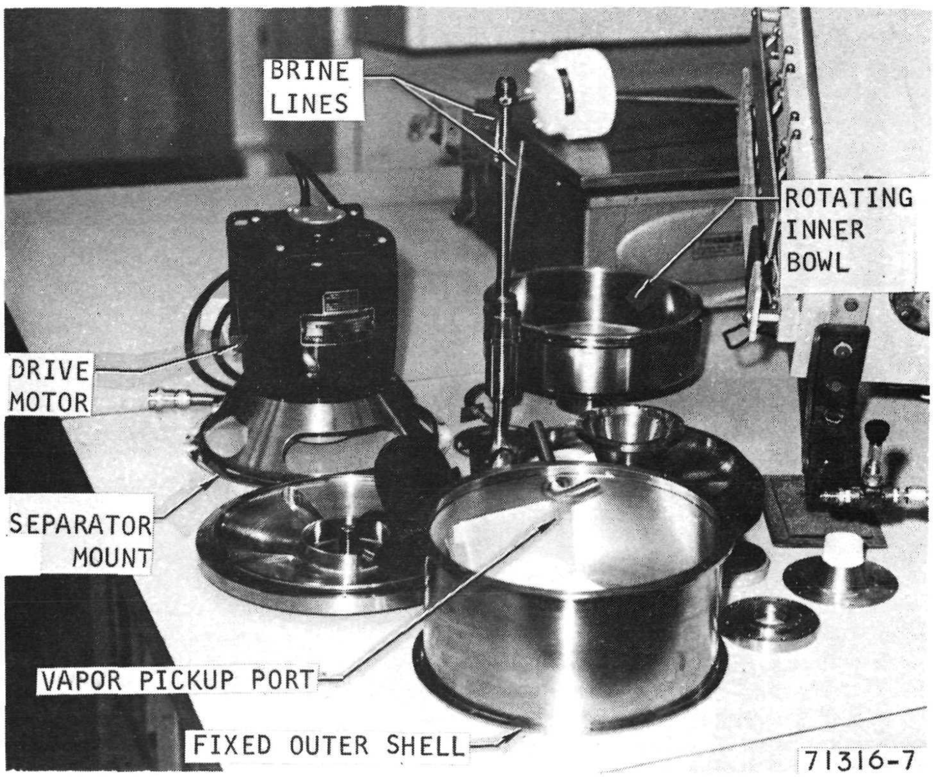
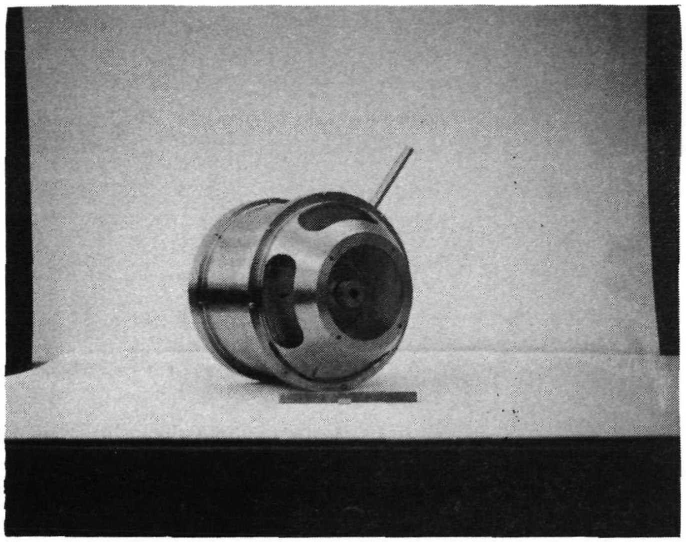
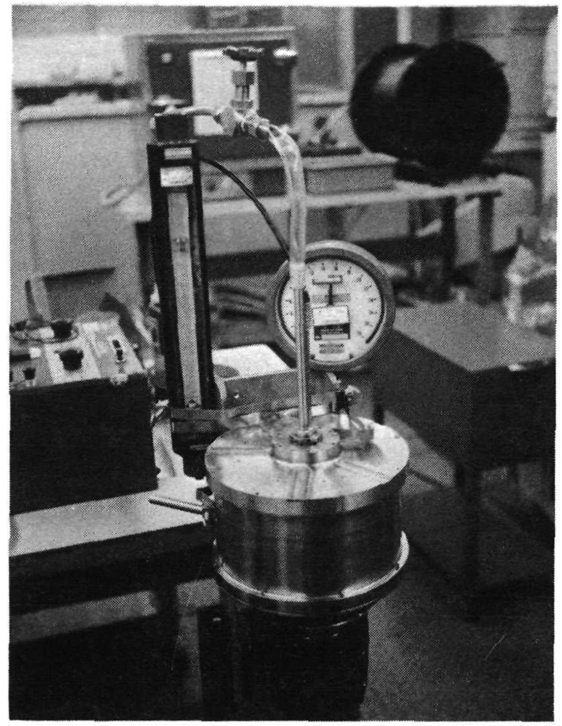


Figure 2-2. Disassembled Separator



A. ASSEMBLED SEPARATOR



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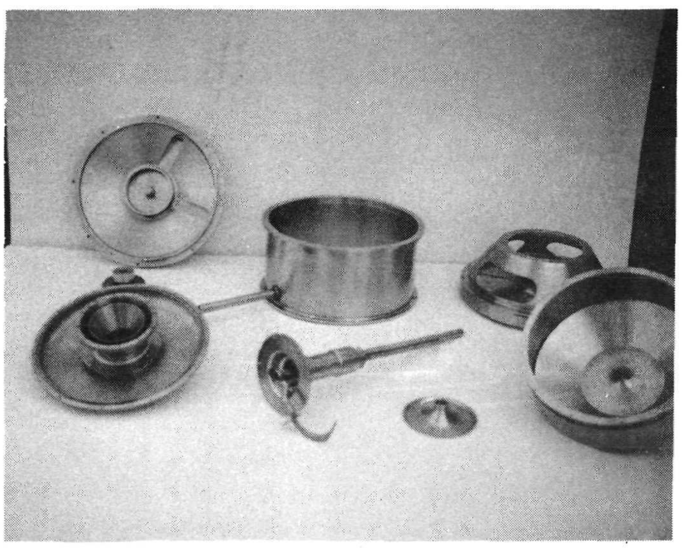
C. SEPARATOR CHECKOUT SETUP



B. SEPARATOR COMPONENTS

Figure 2-3. Phase Separator

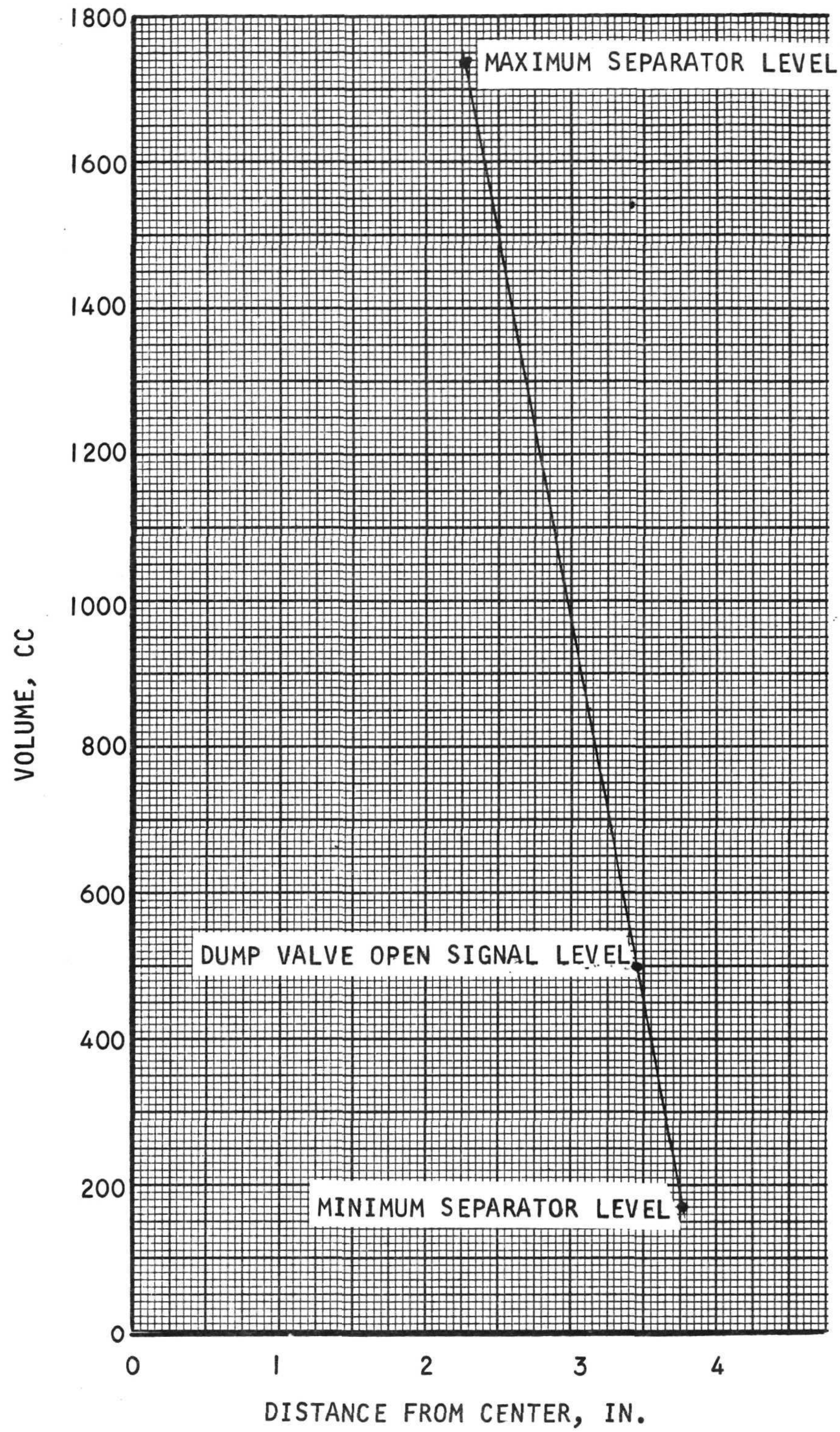


Figure 2-4. Phase Separator Liquid Levels

(d) The radial position of the pitot pickup was extended to increase brine pump outlet pressure and thus increase the brine flow rate. The projected cross section of the pitot tube was decreased and its hydrodynamic shape was improved by adding a downstream fairing to reduce drag. A splash plate was placed on the pitot tube stem to reduce spray and "rooster tailing."

(e) The bearing opposite the motor end was a conventional 440-C sealed bearing lubricated with Krytox; a Hastelloy bearing was used on the magnetic coupling side. The separator was driven by a commercial 1/8-horsepower dc motor from the AiResearch Space Laboratory.

Separator Checkout

After fabrication was completed, the phase separator was checked for functional integrity and performance evaluation. The setup is shown on Figure 2-3(c). All checks were run with water. No water spill into the stationary casing was observed under normal operation up to 2020 rpm. No specific measurement of entrained liquid was made.

Pitot pump performance at separator speeds of 1850 rpm and 2020 rpm is shown in Figures 2-5 and 2-6 for various water levels in the separator. Performance results indicated that a significant increase in brine flow rate could be obtained over the previous design.

Minimum liquid working level also was determined. The pitot tube remained covered with 200 cc of water in the separator when operating at 90-percent operating speed. No further checkout was conducted on the phase separator prior to installation in the breadboard test setup.

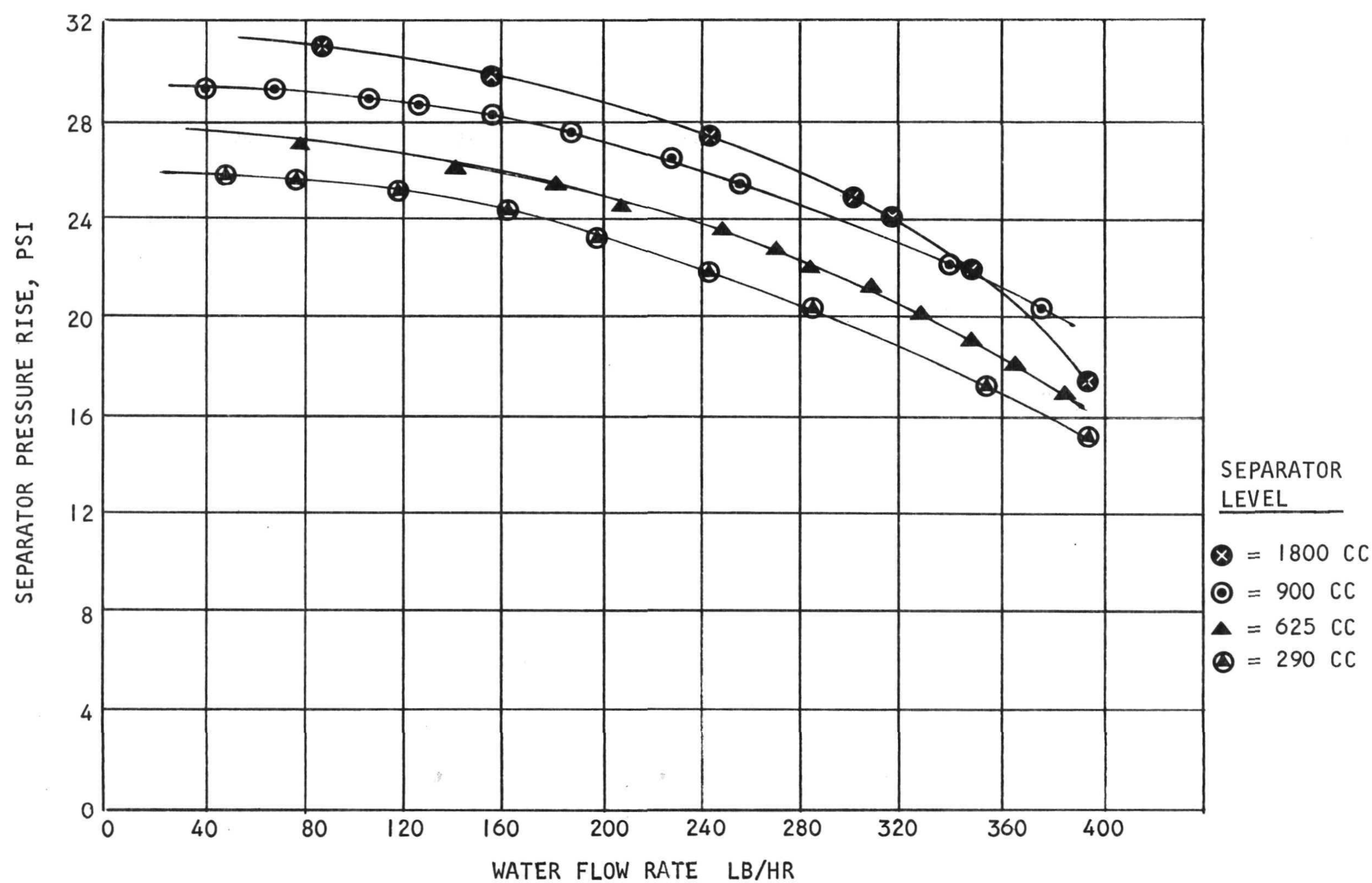


Figure 2-5. Pressure Rise vs Delivery Water Flow Rate at 2020 RPM

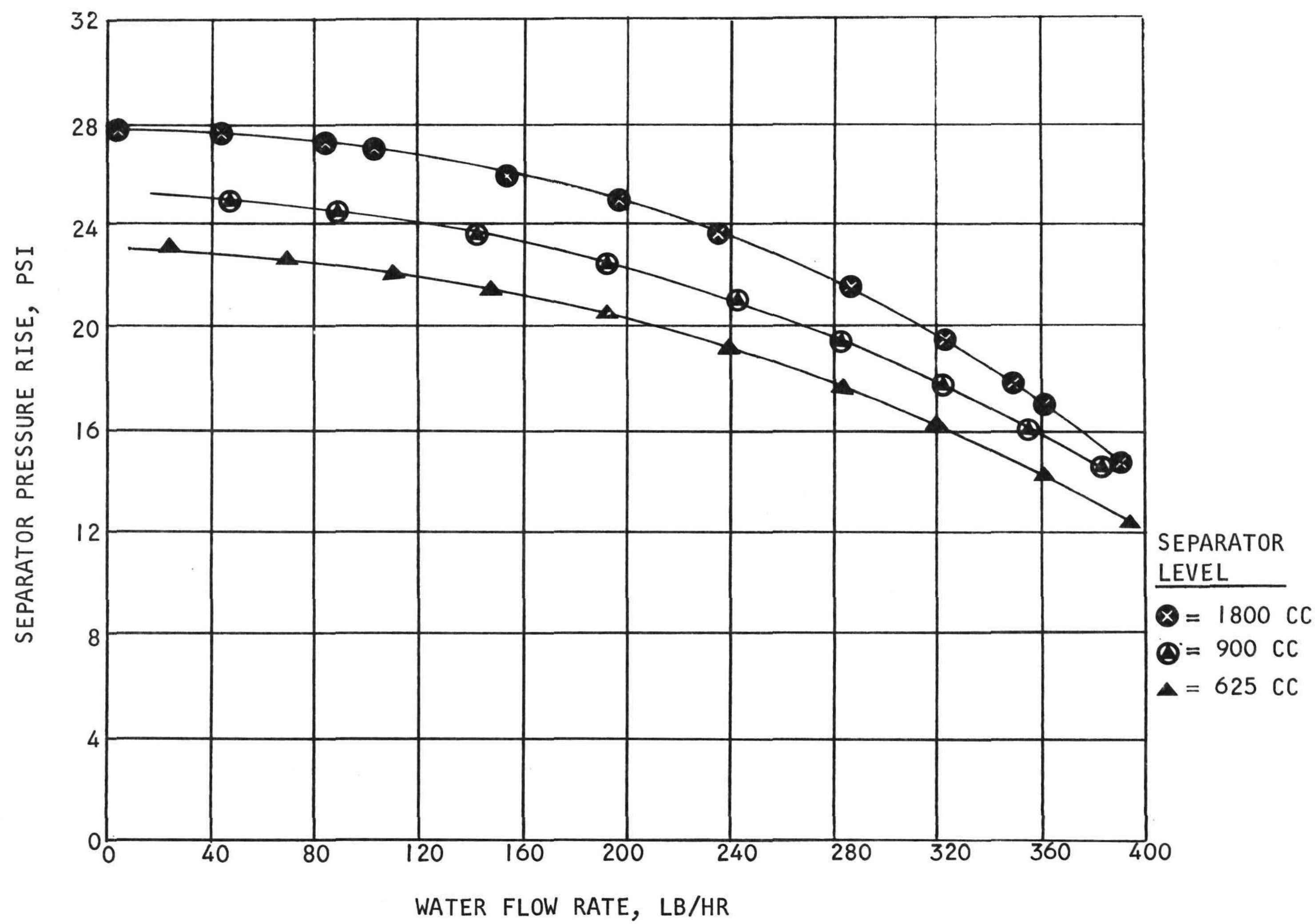


Figure 2-6. Pressure Rise vs Deliver Water Flow Rate at 1850 RPM

FLUID INVENTORY CONTROL SYSTEM MODIFICATIONS

Background

The function of the fluid inventory control system is to determine level and density of the fluid present in the separator assembly, compare these inputs with preset levels, and open or close solenoid valves as necessary for semi-batch continuous operation of the IWRS. Minor problems with the fluid inventory control were encountered in the previous program. The density sensor count rate was found to be dependent on the phase separator liquid level, whereas the minimum level for accurate density measurement was between 400 and 500 cc. This led to the decision to investigate whether low-level density measurement was necessary to system operation.

Scope of Current Program

Figure 2-7 shows the operational sequence of the fluid inventory control system developed for the planned 120-day test in terms of brine density and brine level in the phase separator. This sequence was developed to assure (1) brine dump at a 50-percent concentration for high recovery efficiency and (2) brine processing at low concentration for high processing rates. A typical material balance is presented in Table 2-1.

The plot of Figure 2-7 represents a complete cycle under typical operating conditions. Starting with a separator content of 1500 cc and a brine solids content of 14 percent (Point A), the level sensor maintains a constant level in the separator by addition of urine as water is evaporated from the brine loop. The level remains constant until a brine concentration of 25 percent is reached (Point B). At this point, the density is sensed and this measurement is employed to stop the urine feed. Evaporation continues to take place in the brine loop; since no urine is added, the brine concentration increases at an accelerated rate and the level of the brine in the phase separator drops. The level sensor monitors the separator content. When a level corresponding to a separator content of 600 cc is reached (Point C), the brine concentration will be 50 percent. The level controller then opens the brine loop dump valve and a portion of the brine (400 cc) is drained from the loop. When the separator brine content reaches 200 cc, as measured by the level sensor, the brine

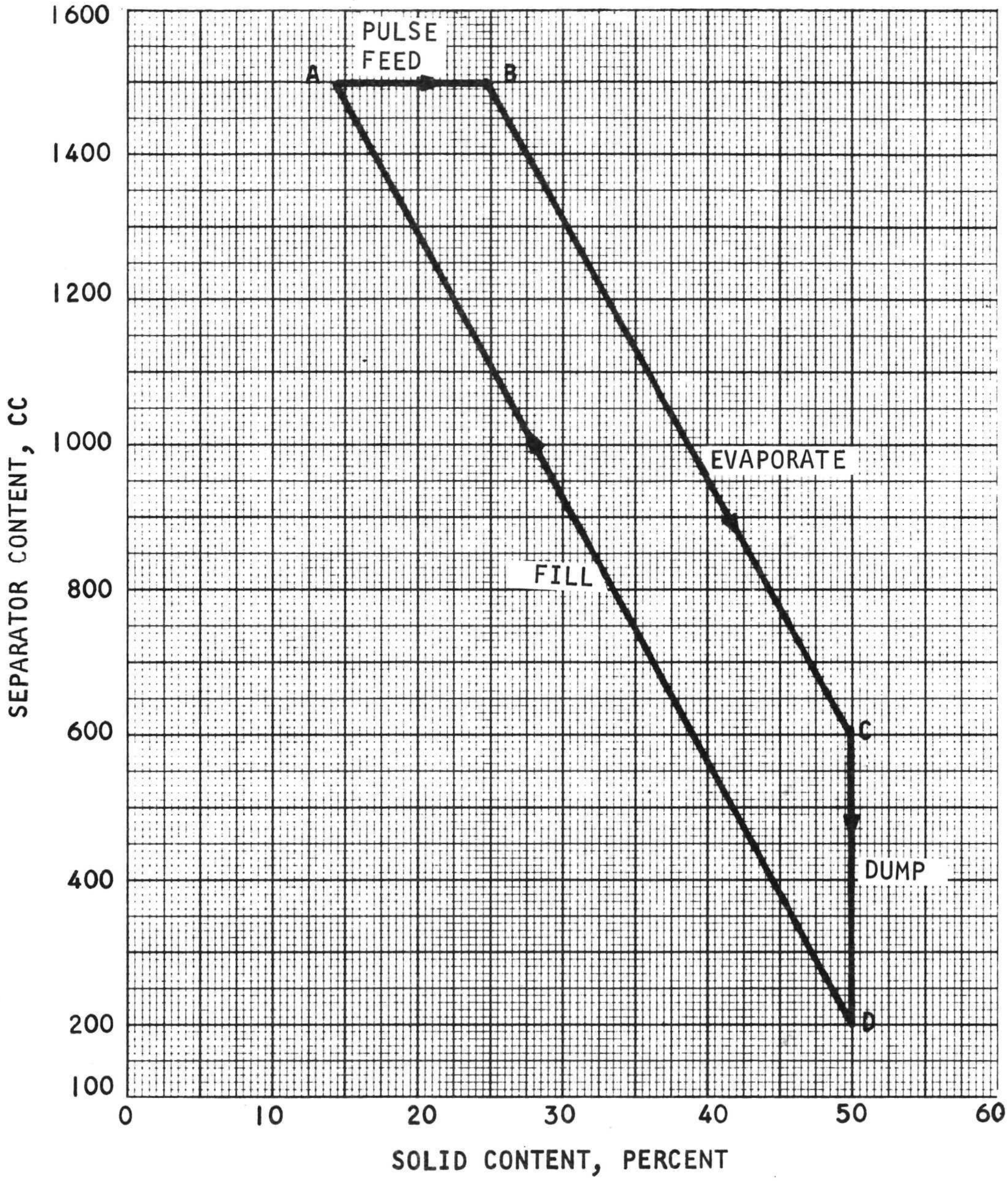


Figure 2-7. Fluid Inventory Control Cycle

TABLE 2-1
MATERIAL BALANCE

	Fluid Inventory, Grams		
	Liquid	Solids	Total
Start Cycle (Point A of Figure 1)	1457.06	239.54	1696.6
Urine Addition (A-B)	4700.64	195.86	4896.5
Subtotal	6157.70	435.4	6593.1
Evaporation (A-B)	4823.19	--	--
Evaporation (B-C)	900.11	--	--
Subtotal	5723.30	--	--
Dump (C-D)	248.8	248.8	497.6
Urine Addition (D-A)	1270.46	52.94	1323.4

dump valve closes and the liquid loop is replenished with urine until the separator content is again 1500 cc (Point A). As before, the brine concentration at this point is 14 percent and the cycle is repeated.

As in the previous breadboard system test, the level and density of the fluid is sensed by Geiger-Mueller tubes located on the separator assembly. These tubes sense gamma rays emitted by radioactive sources located opposite the Geiger tubes. The radiation from each source to the corresponding detector must pass through a portion of the fluid in the separator. The reduction in radiation intensity resulting from attenuation in the fluid is a measure of fluid level or density. The Geiger tubes produce large pulses when excited by gamma radiation. The pulse train from each tube is then converted to pulses of uniform amplitude by the input pulse conditioning circuits.

The conditioned pulses from the Geiger tubes are applied to pulse totalizers, which count the pulses for a fixed time interval. At the end of the sample period, the number stored in the totalizer is compared with preset limits by a digital comparator. The output of the digital comparator drives indicator lamps and provides logic signals to the valve logic panel. In the valve logic panel, the density and level information is routed to preprogrammed comparators. The output of the programmed level comparator is compared to density information and turns on valve drivers, which open or close feed and dump solenoid valves to achieve control action. Manual feed and dump switches are also incorporated in the valve logic panel. A functional block diagram of this system is shown in Figure 2-8. To provide the accuracy necessary for high water recovery efficiency, both the density and level count rates are integrated over a 60-second period.

Limit overrides which count over a 2- to 3-second interval are used to prevent overfill of the bowl and to obviate dumping brine into the vapor loop. To achieve this function, a portion of the control system developed under the previous program was used. In this case, the pulses are integrated to produce an analog level proportional to pulse rate. This analog level is then compared to high and low set points by analog comparators. The outputs of these comparators are connected to lamp drivers and buffer stages. The lamps give a visual

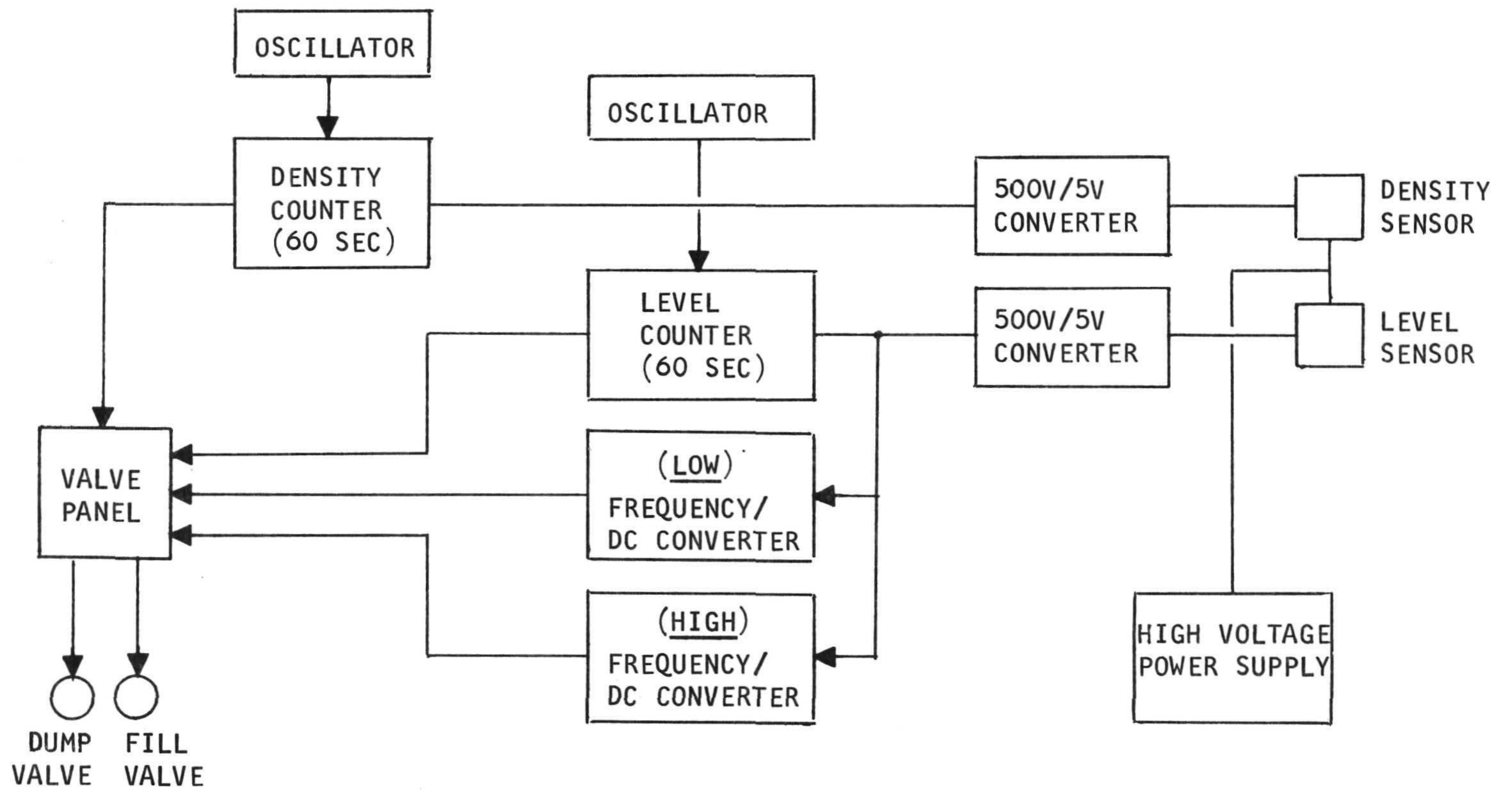


Figure 2-8. Fluid Inventory Control System Block Diagram

indication of fluid level, while the buffers deliver logic signals to the valve logic panel. In the valve logic panel, this fluid level information is compared with preprogrammed action data. The output of this comparison is routed to valve drivers, which open or close solenoid valves to achieve control action.

VAPOR COMPRESSOR MODIFICATIONS

Background

Breadboard testing during the previous program indicated that the vapor compressor motor, which was designed for use in another application, was being operated beyond its design capabilities. As a result, a decision was made to use a motor specifically designed for the vapor compressor in order to perform the 120-day breadboard system test without the operational limitations previously encountered.

Scope of Current Program

The vapor compressor was disassembled after the preceeding breadboard test and the compressor bearings were carefully inspected for evidence of wear. The bearings were found to be in excellent condition. Very slight discoloration was noted, but no signs of wear were evident.

The compressor motor also was disassembled and checked thoroughly to determine the exact cause of motor bearing failure in the previous series of tests. Examination of the bearing installation indicated that inadequate clearance between the bearing outer race and the mounting had been provided and that the bearings had been installed with inadequate preload. These two factors served to severely limit motor life.

It was originally planned to use a higher powered motor for the compressor, but on the basis of the bearing failure analysis it was decided to rework the bearing housing and install precision-type bearings. To establish confidence in the life of the modified motor, a 10-day endurance test with inlet air at 1.0 psia was planned. Endurance testing of the motor and compressor was initiated early in November 1971. The old bearings were reinstalled because new bearings could not be delivered on time. After 61 hours of continuous operation, the compressor stopped operating. Post-test inspection revealed that the outer race of the compressor bearing at the magnetic coupling end had been rubbing against its housing. (The outer race is designed to rotate.) This action resulted in excessive wear of the softer housing material. The entire rotating assembly shifted laterally, until the compressor wheels hit the stationary casings, causing the compressor to stop. Motor performance was entirely satisfactory during the test.

The compressor bearing housing was re-machined and a type 440C stainless-steel ring insert was pressed into the housing where the wear had occurred. The ring was fabricated of the same material as the bearing outer race. The compressor and motor were then reassembled and testing with air was resumed.

The following conditions were maintained constant throughout the remainder of the compressor component test:

Compressor inlet pressure	1.01 psia
Compressor inlet flow	6.4 cfm
Compressor pressure ratio	1.32
Compressor power	151 watts
Compressor housing temperature	154^{0}F
Motor housing temperature	111^{0}F

A performance test with air at 1.0 psia inlet pressure was also conducted. Test results showed that the compressor had the same performance characteristics as obtained in previous breadboard testing (see Figure 2-9).

The endurance test was terminated after the compressor had run continuously for an additional 190 hours, with one voluntary interruption over a weekend. New bearings then were installed and the compressor was considered ready for use in the 120-day breadboard system test.

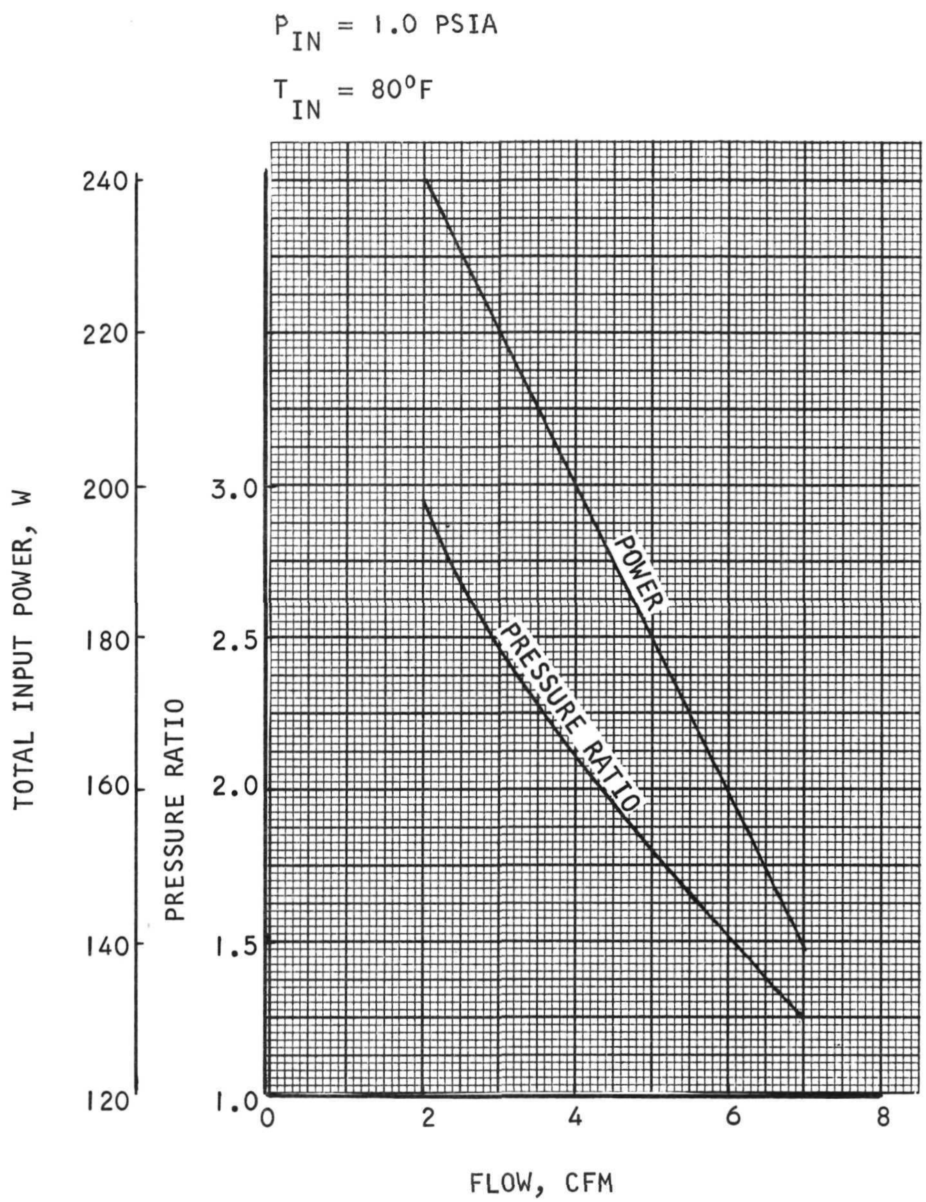


Figure 2-9. Compressor Performance Characteristics

AUTOMATIC MONITORING SYSTEM DEVELOPMENT

Background

Because of the short-term nature of previous breadboard system level testing, monitoring of system parameters was performed manually with continuous surveillance by laboratory test personnel. For the 120-day continuous test planned for the current phase of system level testing, it was decided to add an automatic monitoring system so that (1) the test could be conducted with minimum attention from laboratory personnel and (2) the test could be shut down automatically in a predetermined sequence in case of a critical malfunction.

Scope of Current Program

1. General

The design and development of an automatic control system for use in long-term breadboard system level testing was predicated on the guideline that automatic shutdown would be initiated only when a failure will result in brine spillage or brine loop flow interruption. System shutdown for other types of failures would be initiated manually after observation of a given set of recorded parameters for an indication of improper system operation. This balance of automatic and manual shutdown procedures was designed to allow the system to operate continuously as much as possible.

Automatic shutdown requirements were based on results of the failure modes and effects analysis shown in Table 2-2. The automatic shutdown system monitored selected IWRS parameters for high and low limits and provided a predetermined shutdown sequence if these limits were not met. The system, which is shown schematically in Figure 2-10, consisted of an analog signal conditioner/limit comparator and an automatic shutdown sequencer.

2. Analog Signal Conditioner/Limit Comparator

The analog signal conditioner/limit comparator comprises the following components: four strain gauge pressure transducers with bridge balance units, one temperature reference junction for the appropriate material, two 24-vdc relays, and one 24-channel stamper recorder with mechanical high and low limit switches.

TABLE 2-2
IWRS FAILURE MODE EFFECTS ANALYSIS

Failure Mode	System Effect	Failure Detection	System Response	Effort Required to Continue Testing
Failure causing decrease separator rpm due to binding	Increase in motor amp requirements; decrease in brine loop pressure	Motor amp limit exceeded	Auto shutdown	Repair separator and retest
Compressor failure	Loss of pressure at P5	P5 pressure below allow limit	Auto shutdown	Repair compressor and retest
Controller failure (power loss)	Valves VI and V5 will stay closed; pitot tube will uncover	PI pressure below allow limit	Auto shutdown	Repair controller and restart
Pyrolysis failure	Temp at T6 will decrease. Contamination of potable water system if T6 <250°F	T6 temp below min allow	Auto shutdown	Repair pyrolysis and sterilize water module
Cyclic Accumulator failure	Potable water production stops	Visual--monitoring personnel	None	Determine if failure is due to timer, solenoids, or accum; failed accum requires replacement of accum, decontam of water module, and restart
Vacuum failure	System pressures will increase	P5 pressures increase above limit	Auto shutdown	Repair vacuum and restart
Air leak into system	Decrease in system production rate and efficiency; possible contamination of water module	Increase in gas flow from condenser	Visual--Auto shutdown activated manually	Repair leak; if leak is downstream of pyrolysis reactor, sterilization of water module req'd
Facility power	Valves VI, V2, V4, V7, and V7 close; compressor stop, separator stop, vacuum stop, vapor loop	Pyrolysis reactor min temp indicator	None	Brine loop must be flushed to ensure against blockage; if pyrolysis reactor temp went below

TABLE 2-2 (Cont'd)

Failure Mode	System Effect	Failure Detection	System Response	Effort Required to Continue Testing
Facility power (Cont'd)	press increases due to O_2 inflow; pyrolysis reactor cools			250°F, fresh water must be tested for bacteria; possible complete system cleaning and steriliza-tion req'd
Level Detector	No count indicates high level, controller will close V5 and open V1 until pitot tube is un-covered and P1 decreases	Low P1 pressure; also visual-level high light on panel will always be on count will go to 0	Auto monitor-ing will shut system down	Repair sensor and start
Density Detector	No count indicates high density; low-density brine will be dumped and production effort will drop	Visual--Density high light on panel will always be on and count will go to 0	Auto shutdown activated man-ually	Repair sensor and restart
Urine Control Valve fails open	Urine flow into separ-ator will continue after power to valve is off	Low pressure at P11 when valve signal is off	Auto shutdown	Repair valve and restart
Urine Dump Valve fails open	Separator will empty; pitot tube will uncover	Low pressure at P1	Auto shutdown	Repair valve and restart
Urine Dump Valve fails closed, or plugged dump line	Separator will not empty; density of urine will exceed 50%	Pressure difference between P1 and P13 too great when sig-nal to urine dump is on	Auto shutdown	Repair valve and restart
Urine Control Valve fails closed	No urine flow into separator and pitot tube will uncover	Low pressure at P1	Auto shutdown	Repair valve and restart

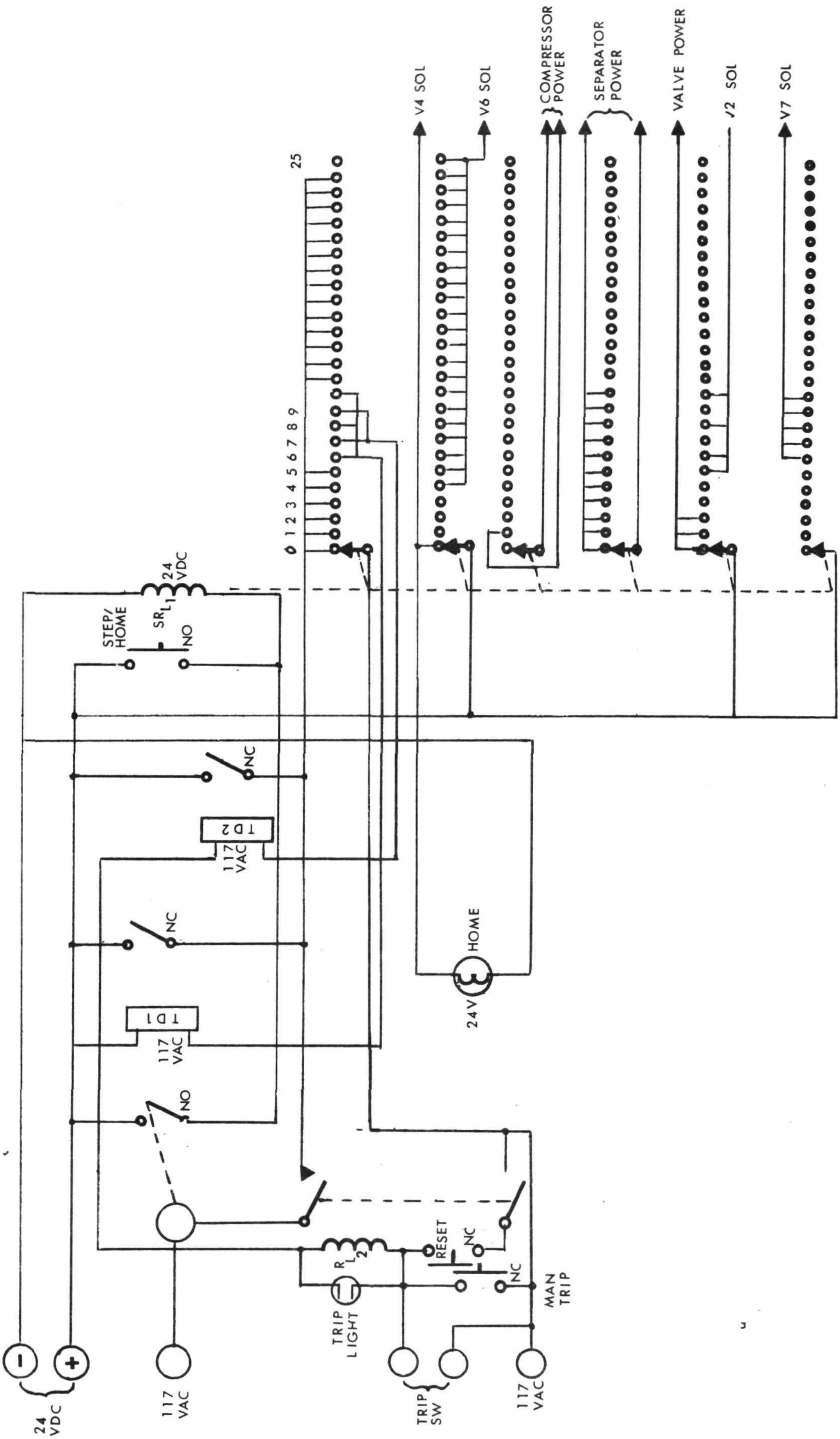


Figure 2-10. Automatic Shutdown System Schematic

The conditioner/comparator operates as follows: The strain gauge pressure transducers receive their excitation signals from a dc power supply. The output signals from these transducers enter the bridge balance units, where an offset voltage is added to the signal. This offset dc output signal is then routed to the input of the recorder, which has two limit switches, mechanically mounted at the 10-percent and 90-percent-full-scale points. If the input signal drives the recorder pen above the 90-percent limit or below the 10-percent limit, these switches will close, starting the shutdown sequencer unit. Each parameter is given zero and span values, which cause the recorder indicator to fall between the 10-percent and 90-percent limits when the corresponding parameter is operating in its normal ranges. Thus, if the value of the parameter falls below or rises above its normal operating range, the automatic shutdown sequencer is started. By using a multichannel recorder, a large number of parameters are monitored for go/no-go limits and are recorded to provide test failure data for analysis.

3. Automatic Shutdown Sequencer

The automatic shutdown sequencer receives the signals from the low and high limit switches and provides a preset, timed sequence of events necessary to safely shut down the breadboard IWRS. This sequencer consists of the following components: a motor driven timer, two electromechanical time delay relays, a latching relay, and a rotary stepping switch.

When a signal is received from either of the limit switches, the latching relay (RL2) closes and is latched closed. The "Trip" light is then on and the timer starts to run. When the timer switch closes, the rotary stepping relay steps one position, causing the compressor inlet valve (V4) to close.

On the next timer switch closure, the rotary stepping relay again advances one position, this time turning off compressor power. On the next timer switch closure, 24-vdc power to the urine feed and dump valves is turned off. As a result, the feed valve (V6) closes and the dump valve (V2) opens.

The flush water valve (V7) then opens, the timer turns off, and the time delay relay (TD1) is pulled in. After TD1 closes, valve V2 is closed and TD2 is pulled in. After TD2 closes, valve V2 is opened and TD1 is pulled in. After TD1 closes, valve V2 closes, and TD2 is pulled in. After TD2 closes, valve V2 opens, and TD1 is pulled in. After TD1 closes, valve V2 closes and separator power is turned off. This concludes the automatic shutdown sequence.

To reset the system, the "Step/Home" button is depressed, causing the stepper relay to advance to position 25. The "Reset" button is then pressed, unlatching relay RL2 and turning off the "Trip" light. The Step/Home switch is then pressed once more, advancing the rotary switch to the "0" or "Home" position. The Home light then comes on, indicating that the system is ready for the next out-of-limit condition.

SECTION 3

BREADBOARD SYSTEM TESTING

GENERAL

A 120-day breadboard-level system test was originally planned for this phase of the IWRS development program. After the system was upgraded as described in Section 2, it was checked for air leakage and instrumentation calibration. This was followed by shakedown runs with distilled water to bring the system into proper operating order.

The planned 120-day test was aborted after 47 days (340.5 hours of operation) because of recurring shutdowns due to a variety of malfunctions. After being modified and refurbished, the breadboard system was operated over a 30-day period. Results of these tests are discussed in detail in this section.

Both tests were conducted in general accord with the IWRS test plan outlined in AiResearch Report 71-8046, previously submitted to NASA. The primary purpose of the test plan was to determine the long term operational and performance characteristics of the system under laboratory conditions.

ABORTED 120-DAY BREADBOARD SYSTEM TEST

Breadboard System Buildup and Shakedown Testing

All breadboard components available from the previous program were carefully examined prior to system buildup into the test setup shown schematically on Figure 3-1. The pH meter and conductivity sensor, used for continuous monitoring of water quality and overall system performance, were replaced with new hardware. The pyrolysis reactor was rebuilt with the same type of rhodium-plated stainless-steel screen catalyst. The breadboard system is shown in various stages in Figures 3-2 through 3-4.

The redesigned phase separator was assembled and leak-checked, as were all other major components, prior to installation in the assembly. After all isolation valves were shut off, the combined brine loop and vapor loop assembly was checked for air leakage from ambient by evacuating the assembly to 0.5 psia and monitoring pressure buildup. A very low leakage rate of 6×10^{-4} lb/hr was obtained. Pressure, temperature, and miscellaneous instruments were then installed in the setup. Prior to the shakedown runs, the complete system was checked to assure that air leakage into the system was minimized.

Initial shakedown runs were conducted with water to check system functions and the instrumentation installation. After about five hours of intermittent operation, the phase separator began to malfunction. Severe vibration was encountered at design speed with the separator bowl full of water. Vibration was less evident when the separator was operated at lower speeds, as well as when lower water levels were used.

Separator vibration apparently was caused by bearing misalignment due to the drag of the water on the pitot tube. This load, in turn, imposed a severe load on the inner race of the lower bearing and tended to rotate it around its diameter.

During the shakedown runs, the automatic shutdown system was triggered intentionally by reducing separator speed. The shutdown sequence operated as planned. Further checkout of the automatic shutdown system was performed during the water calibration tests.

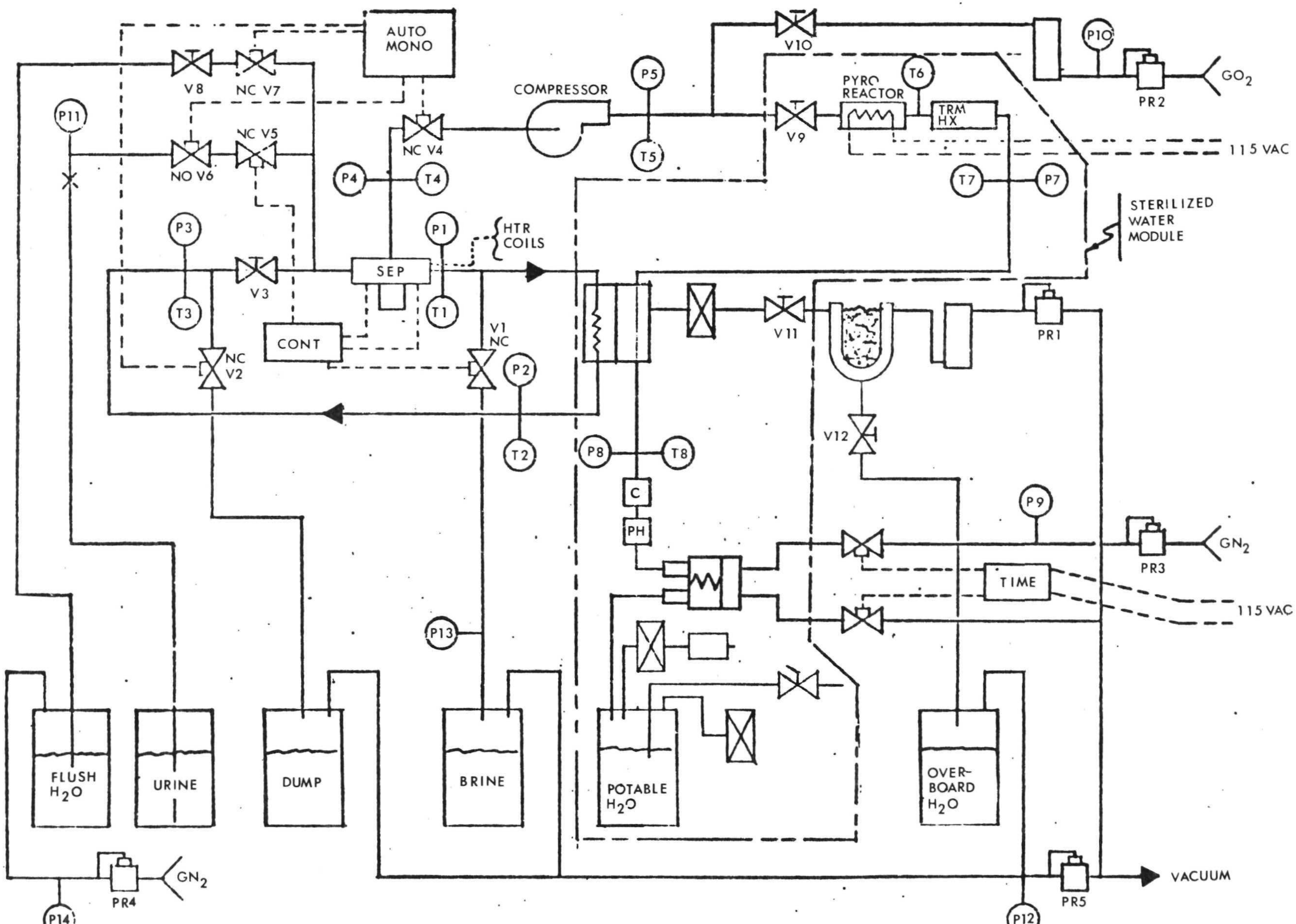
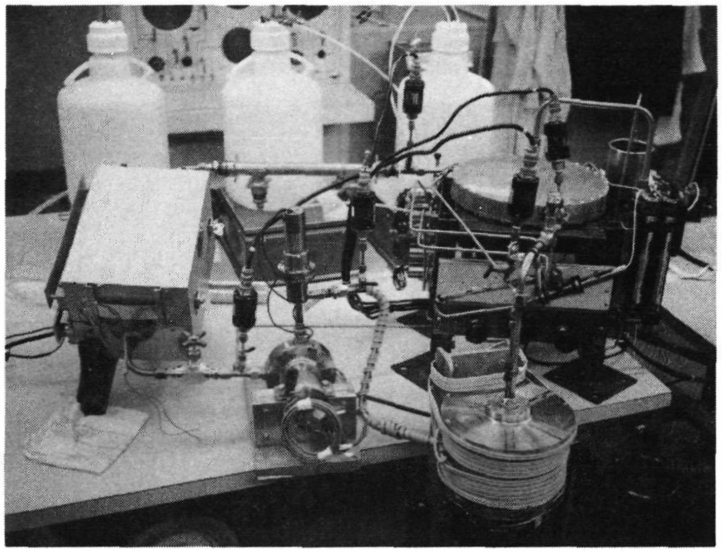


Figure 3-1. Intermediate Water Recovery System Test Setup



F-14836

Figure 3-2. Breadboard System Test Setup

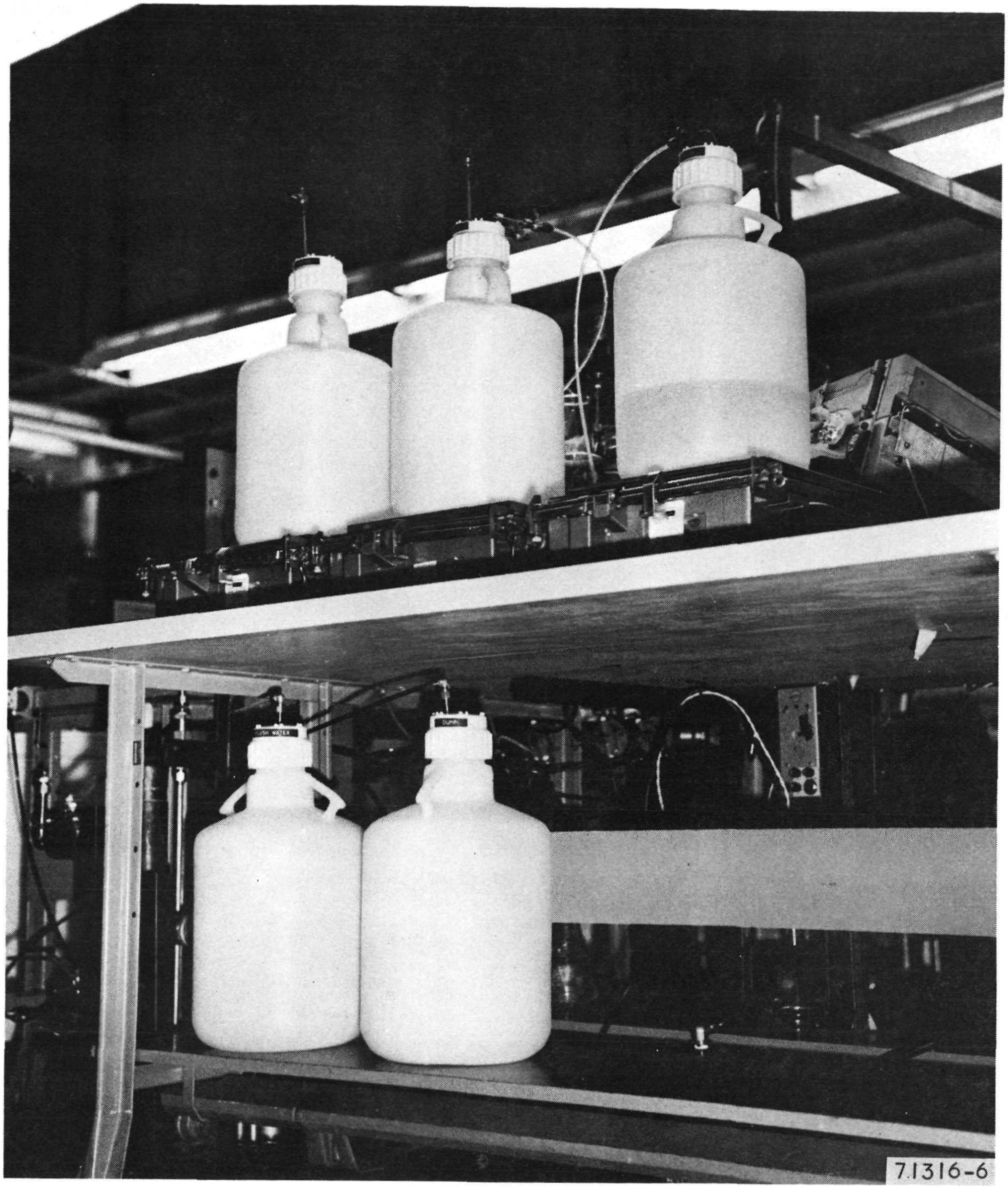


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Figure 3-3. Liquid Holding Tanks and Scales

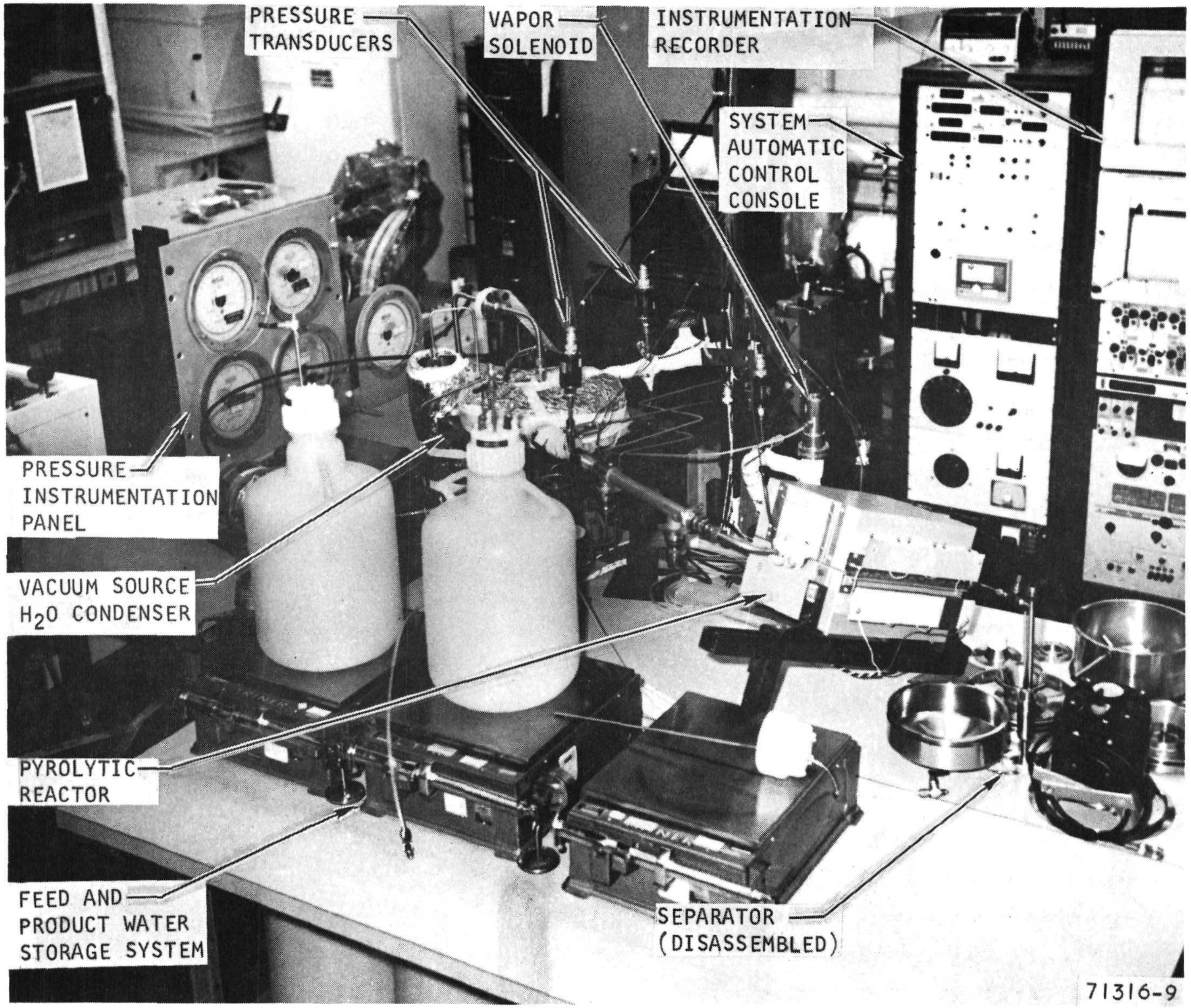

Figure 3-4. IWRS Test Setup

As a result of the separator vibration problem, the upper bearing assembly was redesigned and the separator reworked. In the new configuration, the bearing was mounted directly on the outer casing and the inner race supported the rotating bowl. This arrangement permitted more accurate alignment of the bowl and bearings during assembly. Also, the fluid transfer tube no longer was needed for bearing support.

After rework was completed, the separator was assembled and reinstalled in the breadboard test setup. Further vibration problems experienced were attributed to the separator mounting method. A new mounting arrangement was designed and fabricated, enabling the separator to be rigidly attached to the laboratory floor. Even so, vibration was encountered at the design speed with about 400 cc of water in the separator, necessitating a change in the fluid inventory control cycle.

After rechecking the calibration of the instrumentation, the system was operated with water until thermal and fluid balances were achieved and system operating parameters had stabilized.

Testing of the brine loop with water was conducted as part of the preliminary system checkout to obtain flow performance data for predicting flow rates in the brine loop from pressure readouts at P1 and P2. Test results are plotted on Figure 3-5.

The level controller was adjusted to set a maximum system water fill of 1600 cc, dump at 700 cc, and then refill at 300 cc. The system was sterilized and then operated with water to recheck the thermal balance and level controller operation. Two problems with the separator--excessive brine loop carryover and inability to draw water from the system--were experienced. The problems were solved by sealing an air leak at the soft solder joint of the separator brine return tube. The automatic shutdown system was checked out and found to operate in a satisfactory manner. Sterilization was accomplished by passing live steam through the vapor loop for a period of two hours. The product water collection tanks were sterilized separately in an autoclave. Samples of the product water were tested and found to be sterile.

The system was run with urine for 15 days to calibrate the brine density sensor. A 1.3 percent by weight urine pretreatment solution, manufactured by

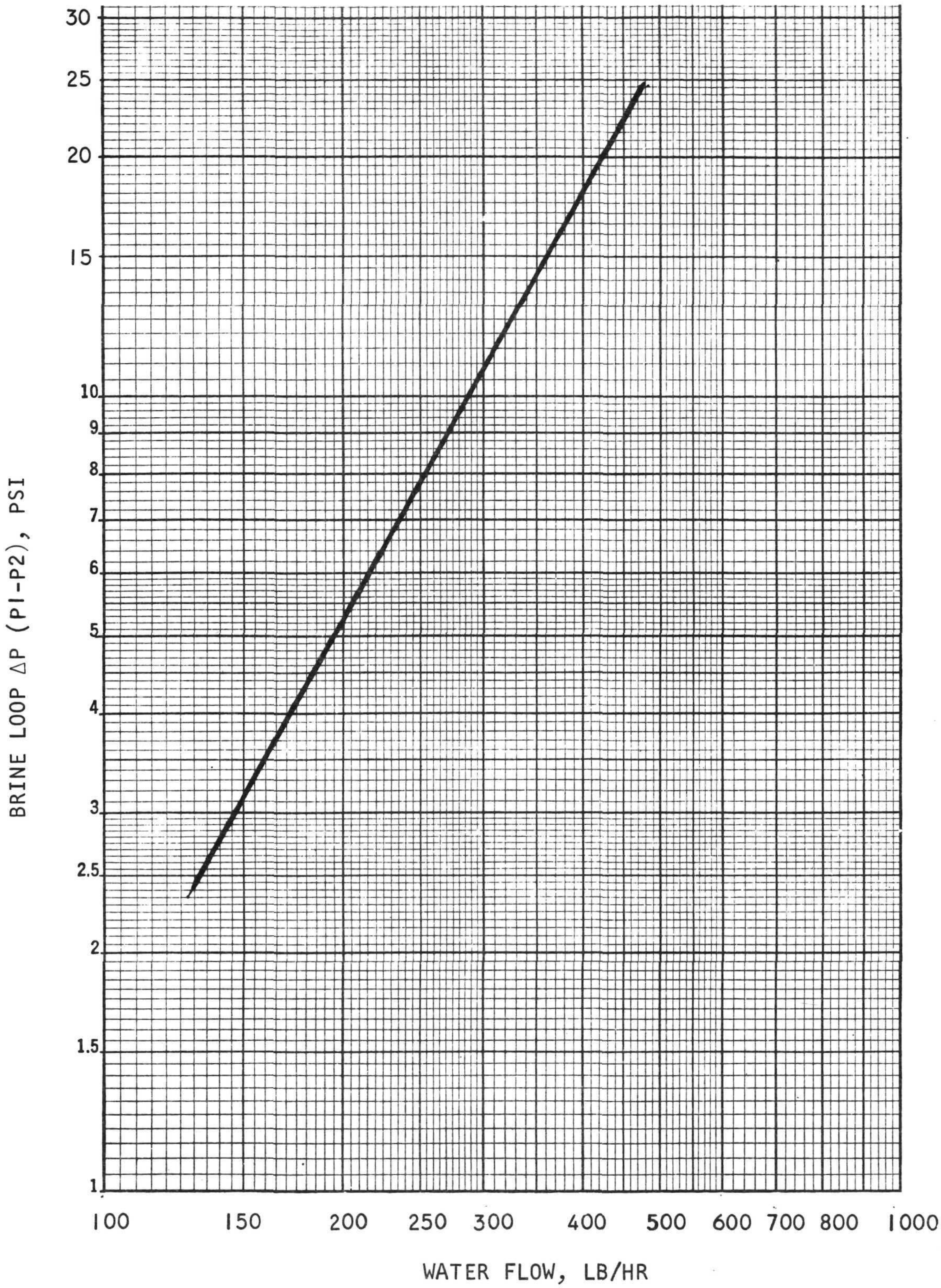

Figure 3-5. Flow vs ΔP of Brine Loop with Water

Chemtric, Incorporated, was added to the stored urine used in the test for the purpose of controlling microbe growth and ammonia generation. Calibration problems with the level/density control electronics and leakage in a condenser joint were encountered. After recalibrating the controls and silver soldering the leaky joint, system checkout was completed. Sterilization of the potable water section after condenser repair was accomplished on 24 April 1972.

Breadboard System Testing With Urine

Urine was introduced into the system on 25 April 1972. The system produced good quality water, but had to be shut down manually after 78.5 hours of operation due to high air leakage and presence of product water odor.

Product water samples taken before shutdown and immediately after shutdown were shipped to NASA for chemical analysis. Results of the analysis are presented in Table 3-1. As indicated in the table, all three samples contained ammonia (as N_2) in excess of the 3 ppm maximum limit.

Examination of the system after shutdown showed that air leaked again at the soft solder joint of the separator brine return tube. The solder was removed and the outlet and return tubes were welded.

On 5 May 1972, testing with urine was resumed. The test continued for 72 hours, at which point the system again was manually shut down because of excessive leakage and odor in the product water. Leakage this time was caused by a fracture on the bottom of the separator. The fracture was welded and the separator bottom remachined.

After repair, the system was restarted with urine on 16 May 1972. A water sample was taken and sent to NASA for analysis. After 107 hours of operation, the system was shut down automatically when the shutoff point of the pyrolysis reactor temperature controller malfunctioned and turned off power to the heater.

After the controller was reset and the system cleaned out, testing with urine was resumed on 22 May 1972. The system produced good quality water initially, but was shut down manually after 27 hours of operation when odor was present in the product water and the water pH factor and conductivity reached 9.2 and 55K ohms, respectively.

TABLE 3-1

NASA WATER ANALYSIS				
Sample Identification: Product Water From Urine Water Recovery System				
Source: AiResearch	Date Sample Taken	4-26-72	4-27-72	4-28-72
ANALYSIS	SPECIFICATION LIMITS	ANALYSIS RESULTS		
pH	6-8	0.46	8.18	8.70
Resistivity (Megohm— cm at 25 deg C)	Ref. only	0.033	0.008	0.006
Total Solids, ppm	500	26.6	4.0	61.4
Organic Carbon, ppm	100	9.0	1.5	15.0
Inorganic Carbon, ppm	Ref. only	7.0	94.0	210
Cadmium as Cd, ppm	0.01	0.05	<0.01	<0.01
Chromium as Cr^{+6}, ppm	0.05	<0.01	<0.01	<0.01
Copper as Cu, ppm	1.00	<0.05	0.10	0.12
Iron as Fe, ppm	0.3	≤0.1	<0.1	<0.1
Lead as Pb, ppm	0.05	<0.5	<0.5	<0.5
Magnesium as Mg, ppm	Ref. only	0.34	≤0.01	≤0.01
Manganese as Mn, ppm	0.05	<0.05	<0.05	<0.05
Mercury as Hg, ppm	0.005	<0.05	<0.005	<0.005
Nickel as Ni, ppm	0.05	<0.05	<0.5	<0.5
Potassium as K, ppm	Ref. only	1.6	0.41	0.17
Silver as Ag, ppm	0.05	<0.05	<0.05	<0.05
Sodium as Na, ppm	Ref. only	0.19	0.09	<0.01
Zinc as Zn, ppm	5.0	<0.01	<0.05	<0.04
Ammonia as N, ppm	3.0	4.5	12.5	45
Flouride as F^-, ppm	2.0	0.56	0.60	0.58
Nitrate as NO_3^-, ppm	TBD	0.18	0.36	0.48
Sulfate as SO_4^{-2}, ppm	450	4.0	15.5	19.5

The test was restarted with urine on 24 May 1972 and continued for 13 hours, at which point the system was automatically shut down due to excessive vapor circuit pressure. Examination of the system revealed that the outer shell of the pyrolysis reactor had imploded. The disassembled reactor is shown on Figure 3-6. Inspection of the rhodium-plated screens used as the catalyst showed that some were badly corroded. Photomicrographs of the screens are presented in Figure 3-7. New screens would take 3 to 4 weeks to fabricate; therefore, this catalyst was replaced with a readily available catalyst made of 0.5 percent ruthenium on alumina pellets.

After repairs were completed, the system was restarted with urine on 4 June 1972 and ran for 3.25 hours before shut down due to malfunctioning of the controller. The system was found to be completely saturated with urine as a result of a bad solder joint in the liquid level control circuit.

System cleanup, repair, and checkout were performed before restarting with urine on 9 June 1972. After 39.75 hours of operation, automatic shutdown occurred as a result of excessive air leakage into the system, which, in turn, caused the system to produce poor quality water with a urine odor. Leakage was traced to a faulty compressor inlet valve.

The breadboard system test was discontinued on 10 June 1972, after 340.5 hours of operating time were accumulated. After being cleaned and flushed, the system was dismantled and critical components inspected. The disassembled vapor compressor is shown on Figure 3-8.

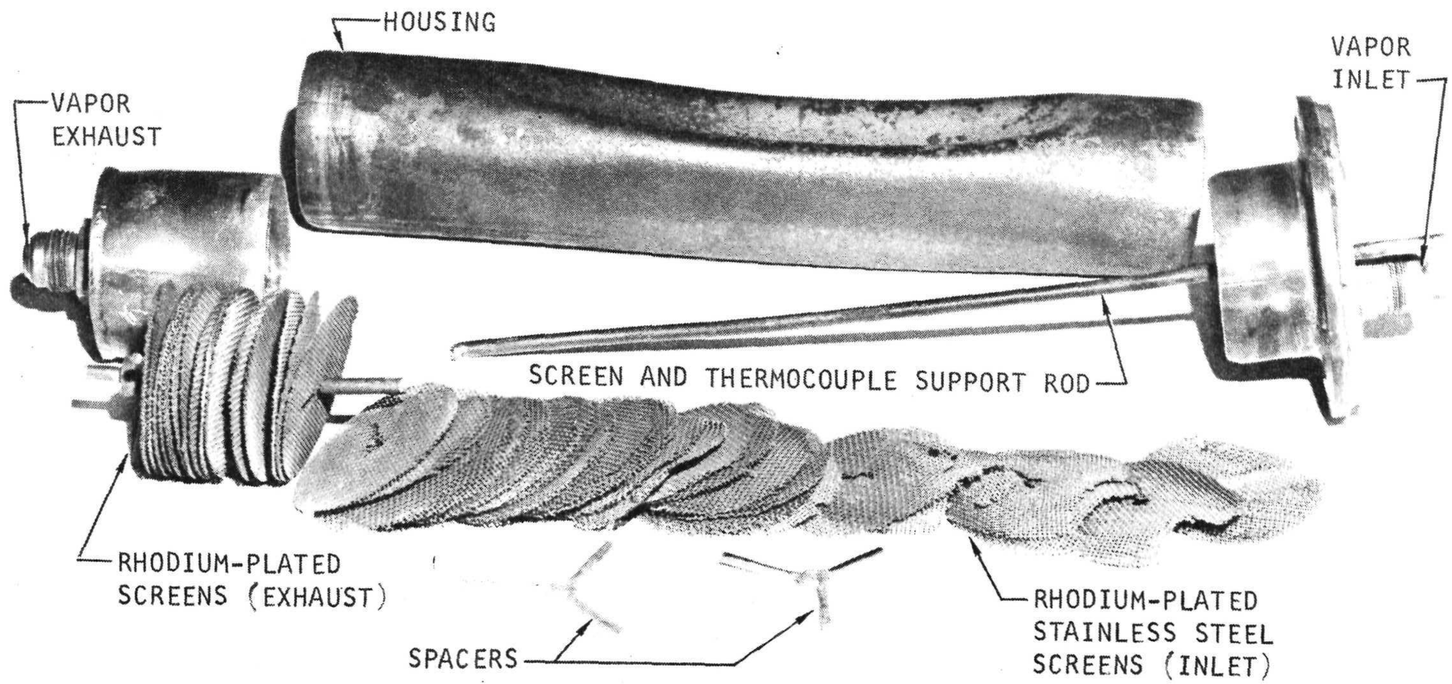

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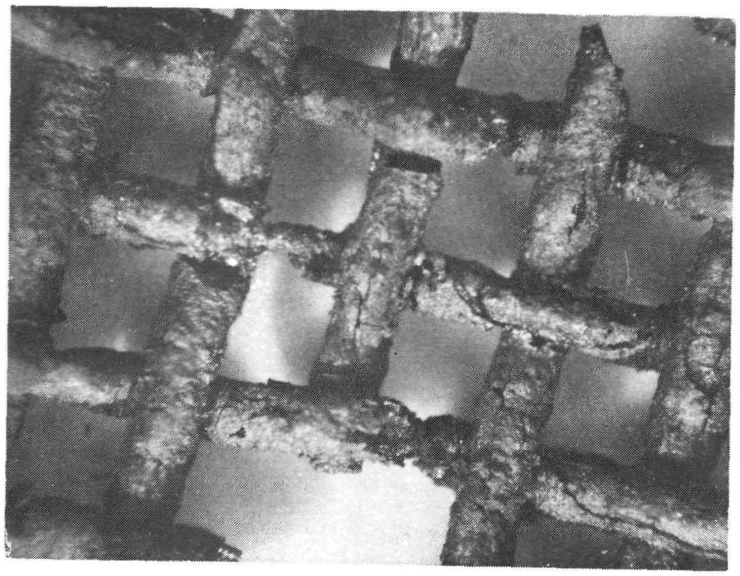
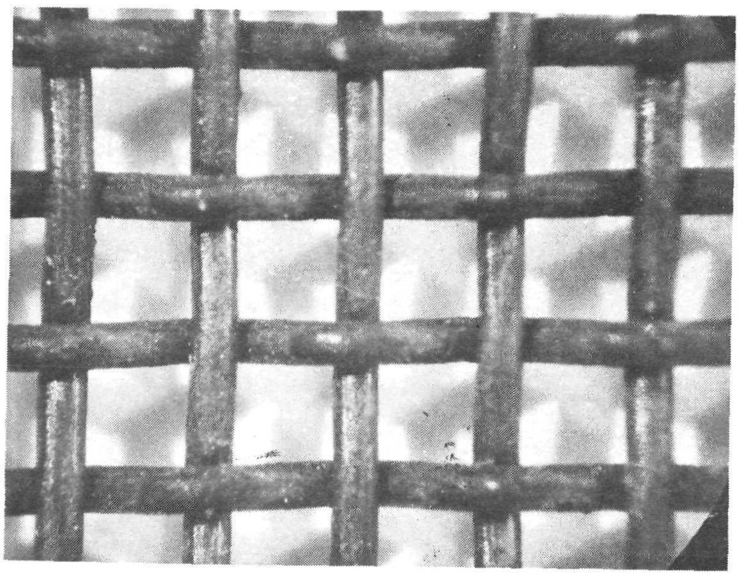
Figure 3-6. Breadboard Pyrolysis Reactor after Collapse



INLET END



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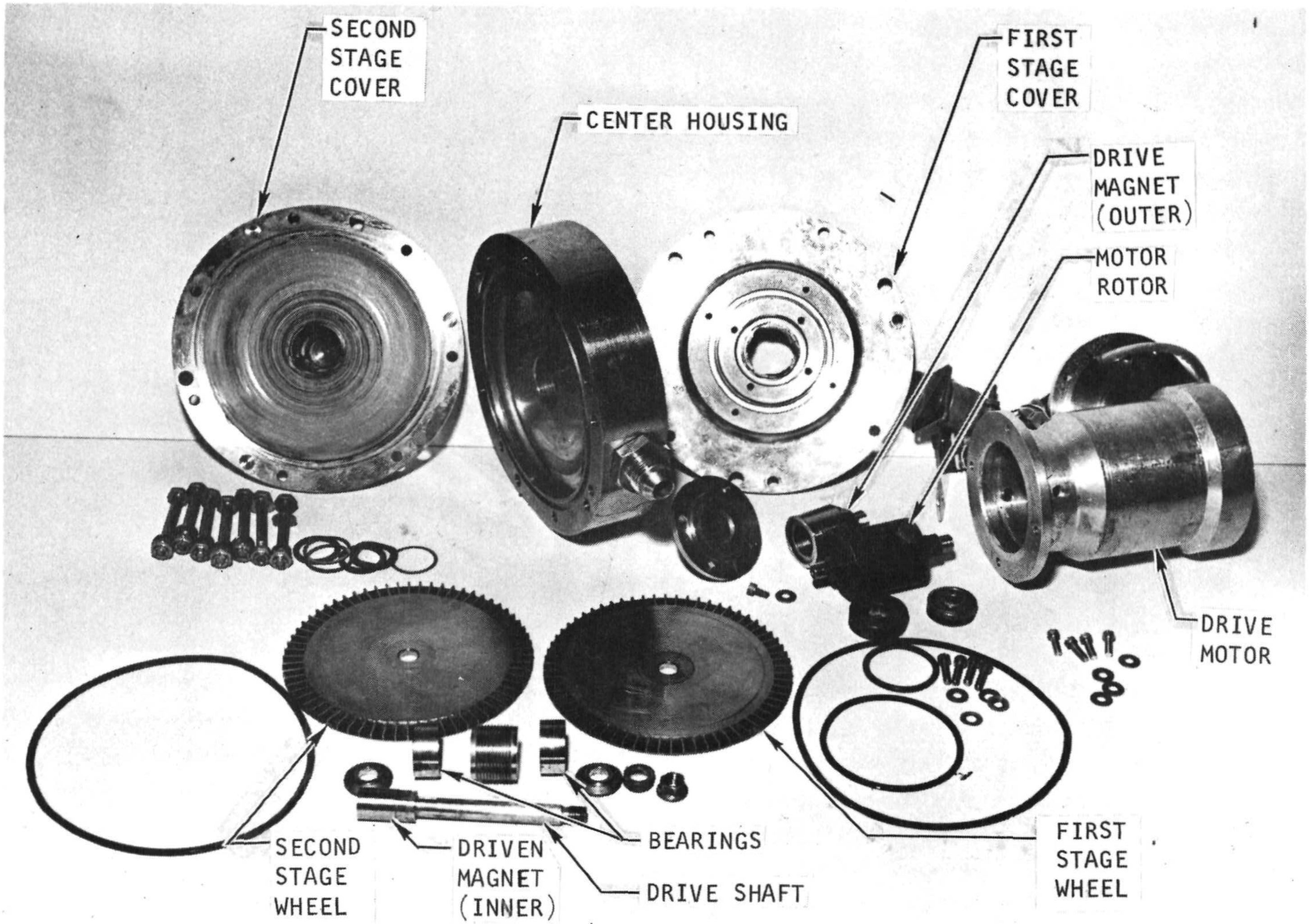
OUTLET END

Figure 3-7. Catalyst Substrate Screen



72069-1

Figure 3-8. Vortex Compressor--Disassembled

30-DAY REFURBISHED BREADBOARD SYSTEM TEST

Background

During contract negotiations for development of the Wash Water Recovery System (WWRS) under NASA Contract NAS 9-13026, AiResearch agreed to conduct a 30-day IWRS breadboard-level test, with the system modified and refurbished to avoid the repeated shutdowns encountered in the aborted 120-day breadboard system test. The main objective of the test was to expose the rotating machinery in the brine and vapor loops to long-term operation. Contract NAS 9-11996 was extended until completion of the 30-day test. The basic modifications made to the breadboard setup prior to initiating the 30-day test are described below.

Component Modifications

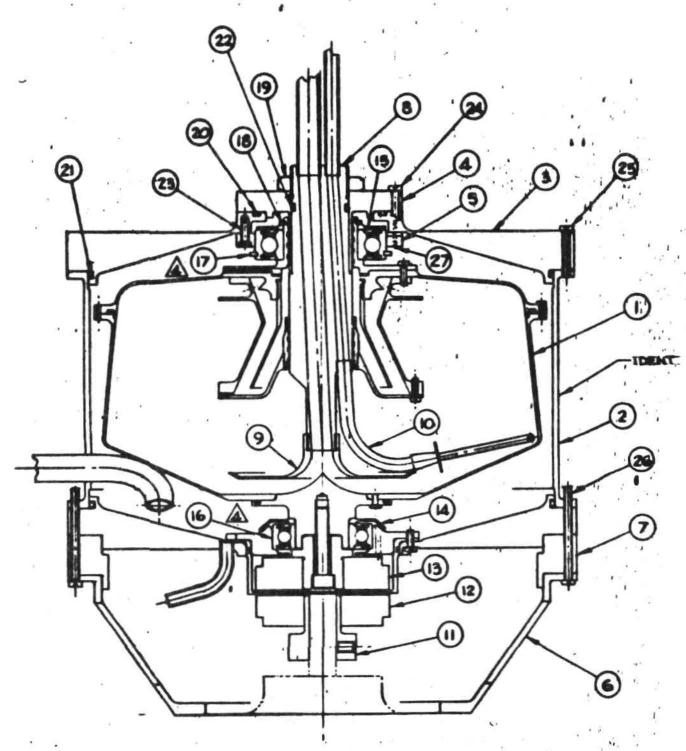
1. Phase Separator Modifications

The basic modification to the phase separator involved the bearings; a cross-section of the modified separator is shown in Figure 3-9. The lower bearing arrangement was changed to minimize the severe vibration problem encountered during previous testing. The existing inner bowl and bottom plate were used with slight modifications. Other refinements, shown in Figures 3-10 and 3-11, included slingers on both bearings to reduce corrosion and a reworked Teflon sleeve to decrease carryover.

2. Control System Modifications

The trip signal of the automatic shutdown system was removed from the 24-channel Brown stamper recorder. All critical parameters were monitored continuously on an 8-channel continuous recorder and a 24-channel stamper recorder. Figures 3-12 and 3-13 show the parameters. The IWRS could be shut down automatically by pressing the "Manual Trip" button on the "Automatic Shutdown" panel of the control console. In addition, a pressure switch was installed in the brine loop at P1. When the brine pressure dropped below a predetermined value, V6 was closed, stopping urine feed. This prevented overfilling the separator.

Since system operation was to be monitored around the clock by test technicians, manual adjustments could be made to controls whenever measured parameters fell outside normal operating limits. If trouble shooting indicated a critical component malfunction, the system could be shut down manually to the extent considered necessary to correct the malfunction. All other components in the system would continue to operate while the malfunction was investigated.



QTY REQD	ITEM NO.	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	SYM
2	27		MS 9389-06	PIN	
12	26		MS 51957-37	SCREW	
12	25		MS 51957-34	SCREW	
8	24		MS 51957-31	SCREW	
8	23		MS 51957-15	SCREW	
1	22		MS 9068-118	PACKING	
1	21		NAS 1593-173	PACKING	△
1	20		MS 9068-141	PACKING	△
1	19		AN 924-12C	NUT (REWORKED TO .24-.26 THICK)	△
1	18		626-328-3010	RING, RETAINING	
1	17		9107 PPG	BEARING (UPPER) FAFNIR	△
1	16		9105 PP	BEARING (LOWER) FAFNIR	△
1	15		SK 65218-1	SLINGER, UPPER	
1	14		SK 65219-1	SLINGER, LOWER	
1	13		SK 65223-1	MAGNET ASSY, INNER	
1	12		518751-1	MAGNET S/N 107	△
1	11		PA 121224	ADAPTOR ASSY	△
1	10		PA 121223	TUBE ASSY	△
1	9		PA 121217	BELL, SHAFT	△
1	8		SK 65224-1	SHAFT	△
1	7		SK 65225-1	ADAPTOR, SUPPORT	
1	6		PA 121225	SUPPORT	△
1	5		SK 65215-1	RETAINER, BEARING	△
1	4		SK 65216-1	CAP, TOP	
1	3		SK 65214-1	COVER, TOP	△
1	2		SK .5234-1	CASING ASSY, LOWER	
1	1		SK 65212-1	ROTOR ASSY	

← ASSY

PARTS LIST

NCS CLASS II

HEAT TREATMENT | PROCESS

F. L. Wilkerson 8-23-72

9/23/72

AIRESEARCH MANUFACTURING COMPANY

SEPARATOR ASSY, WATER RECOVERY

D 70210 SK 65235

SCALE 1/1 SHEET 1 OF 1

Figure 3-9. Water Separator Assembly

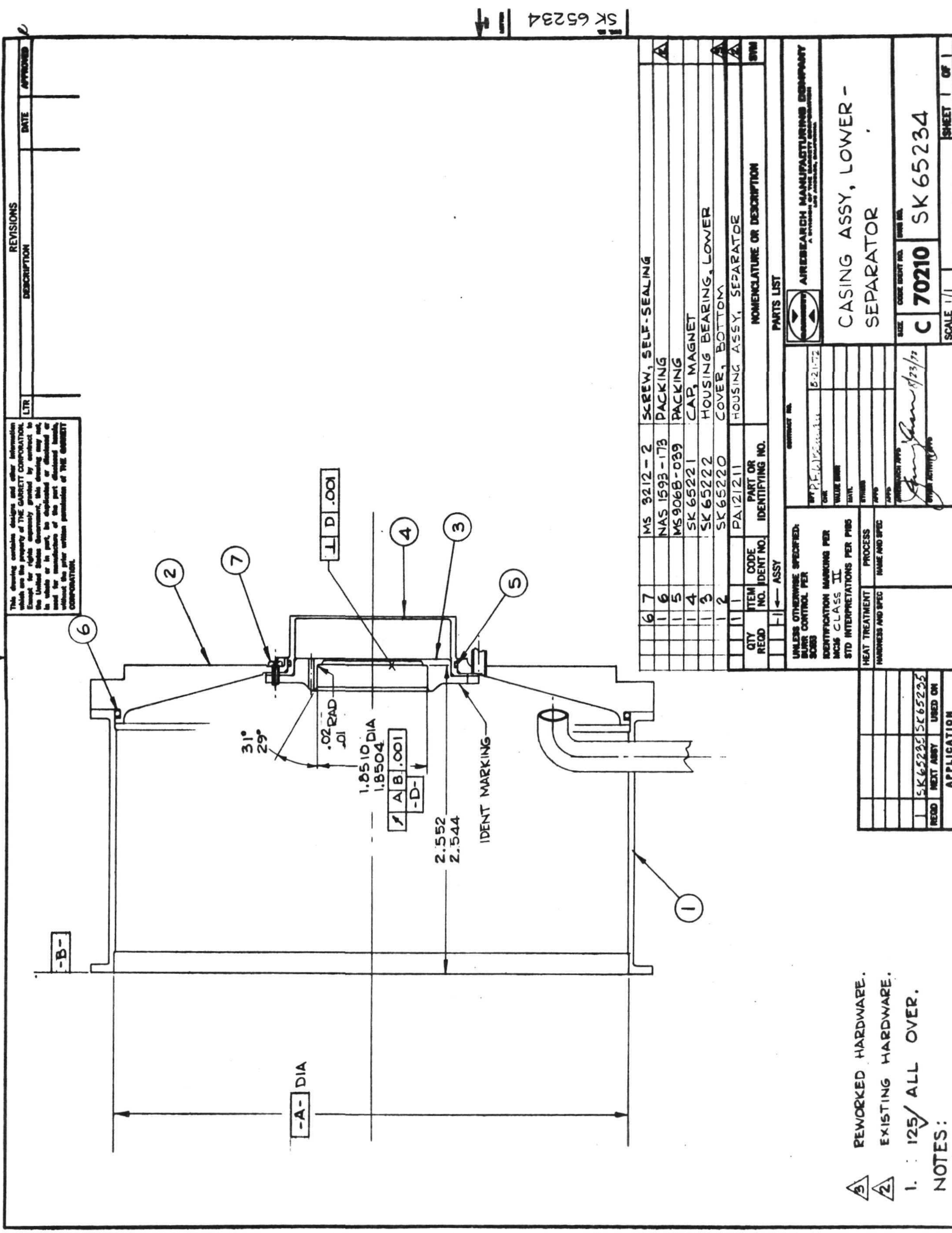


Figure 3-10. Lower-Separator Casing Assembly

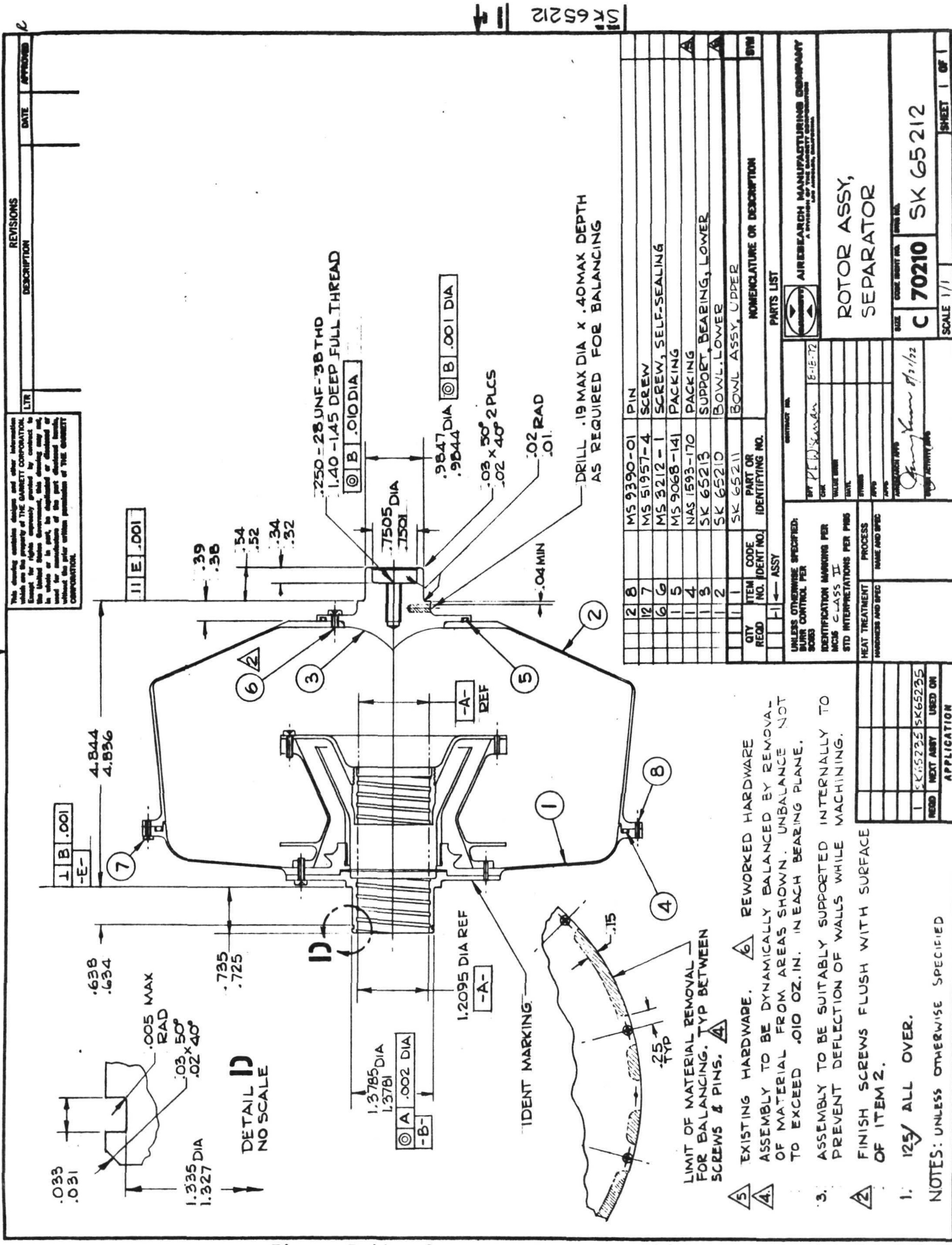


Figure 3-11. Separator Rotor Assembly

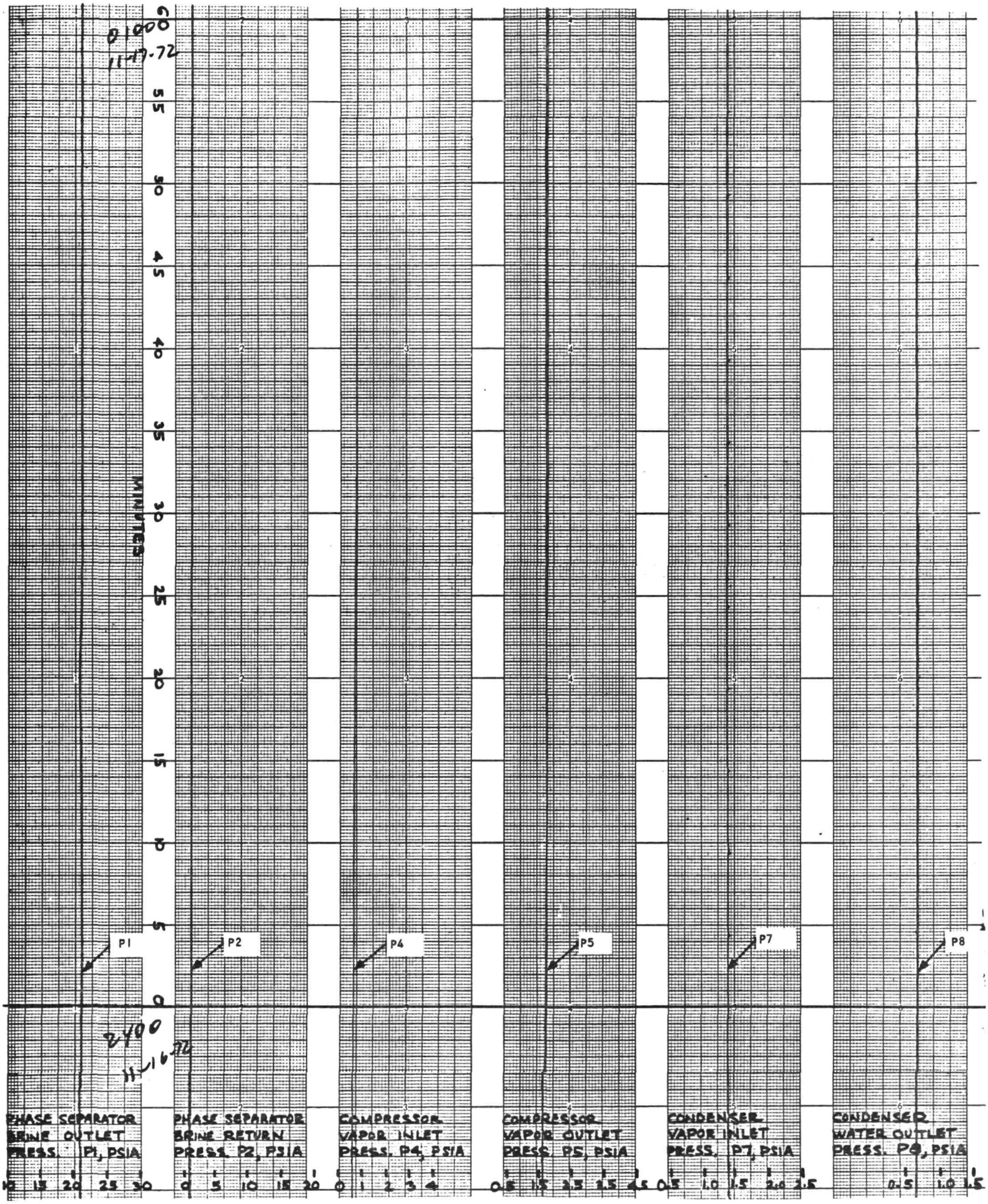


Figure 3-12. Continuously Recorded Pressure Parameters (Pulse Feeding Urine into Separator)

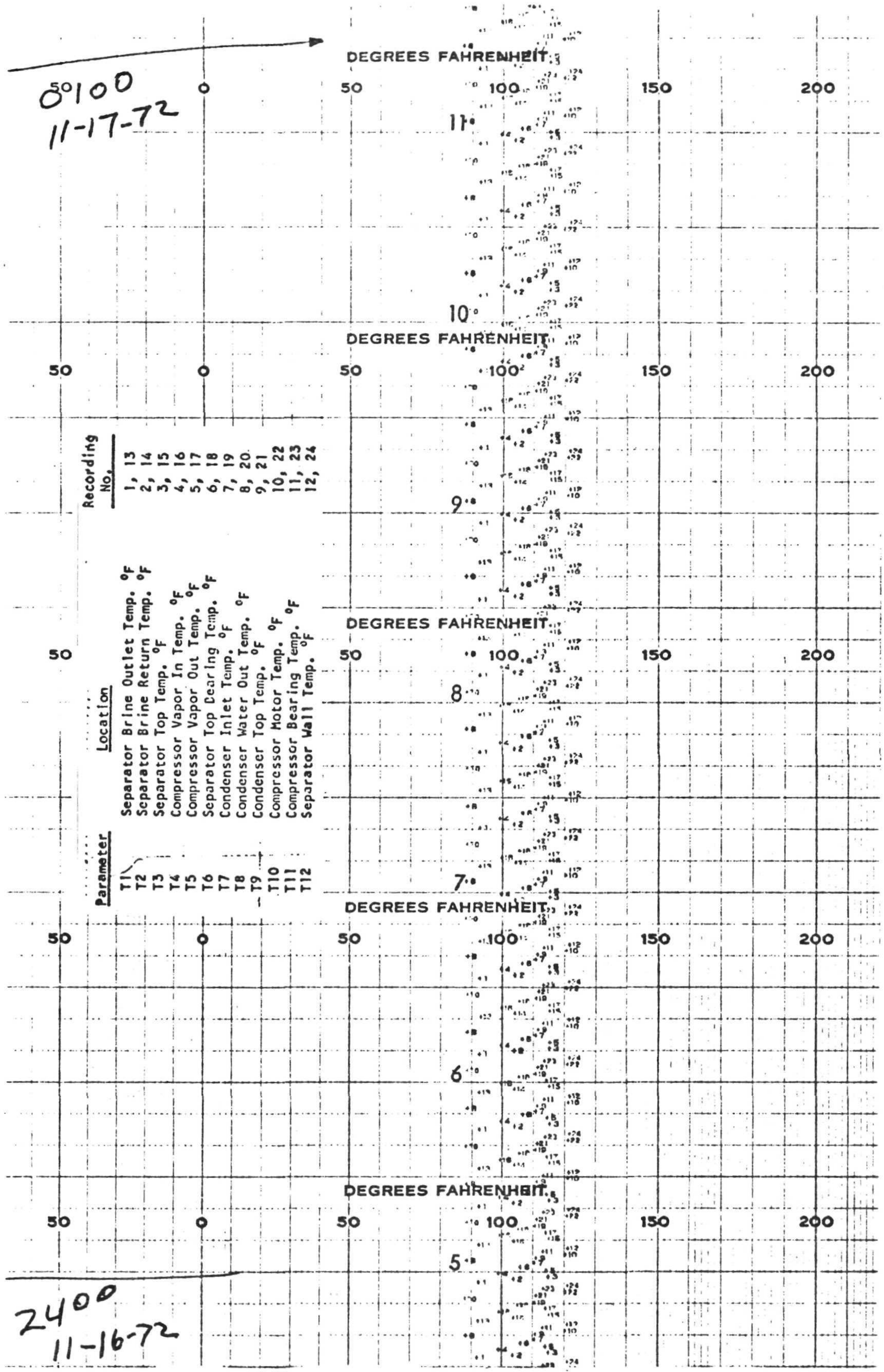


Figure 3-13. Continuously Recorded Temperature Parameters

3. Vapor Compressor Refurbishment

The vapor compressor was disassembled, cleaned, and reassembled with new precision-type bearings, properly preloaded. No modifications were made to the unit.

4. Pyrolysis Reactor Modifications

A new pyrolysis reactor was fabricated, using a similar rhodium-plated screen catalyst bed to that in the previous reactor. Refinements were made in assembling and spacing the screens to increase reactor efficiency. As depicted in Figure 3-14, 50 screens were packed in 5 sets. Six coarse-mesh screens were used to separate the sets of fine-mesh screens.

5. Brine Density

A new in-line brine density sensor was fabricated to avoid the sensitivity problem encountered with the previously-used sensor, which was located on the phase separator. The new sensor was located immediately downstream of the phase separator brine outlet port. The nucleonic source and detector were placed on the flat sides of the cavity shell, shown in Figure 3-15, and were covered by a lead shield.

6. System Test Setup

Unnecessary equipment and lines used in the previous breadboard arrangement were eliminated to minimize pressure losses. Photographs of the 30-day breadboard system arrangement and identification of the major components are presented in Figures 3-16 and 3-17. A closeup view of the instrumentation and control panels is shown in Figure 3-18. Locations of pressure transducers and temperature thermocouples placed at various points in the system test setup are shown in Figures 3-19 through 3-25.

Major components and lines in the refurbished breadboard system were thermally insulated to reduce heat losses and assist in maintaining proper heat balance where required. The areas where thermal insulation was applied are shown in Figures 3-26 through 3-29. For more accurate analysis of the product water, a sampling valve (see Figure 3-21) was installed in the cyclic accumulator discharge line in place of the in-line pH and conductivity sensors.

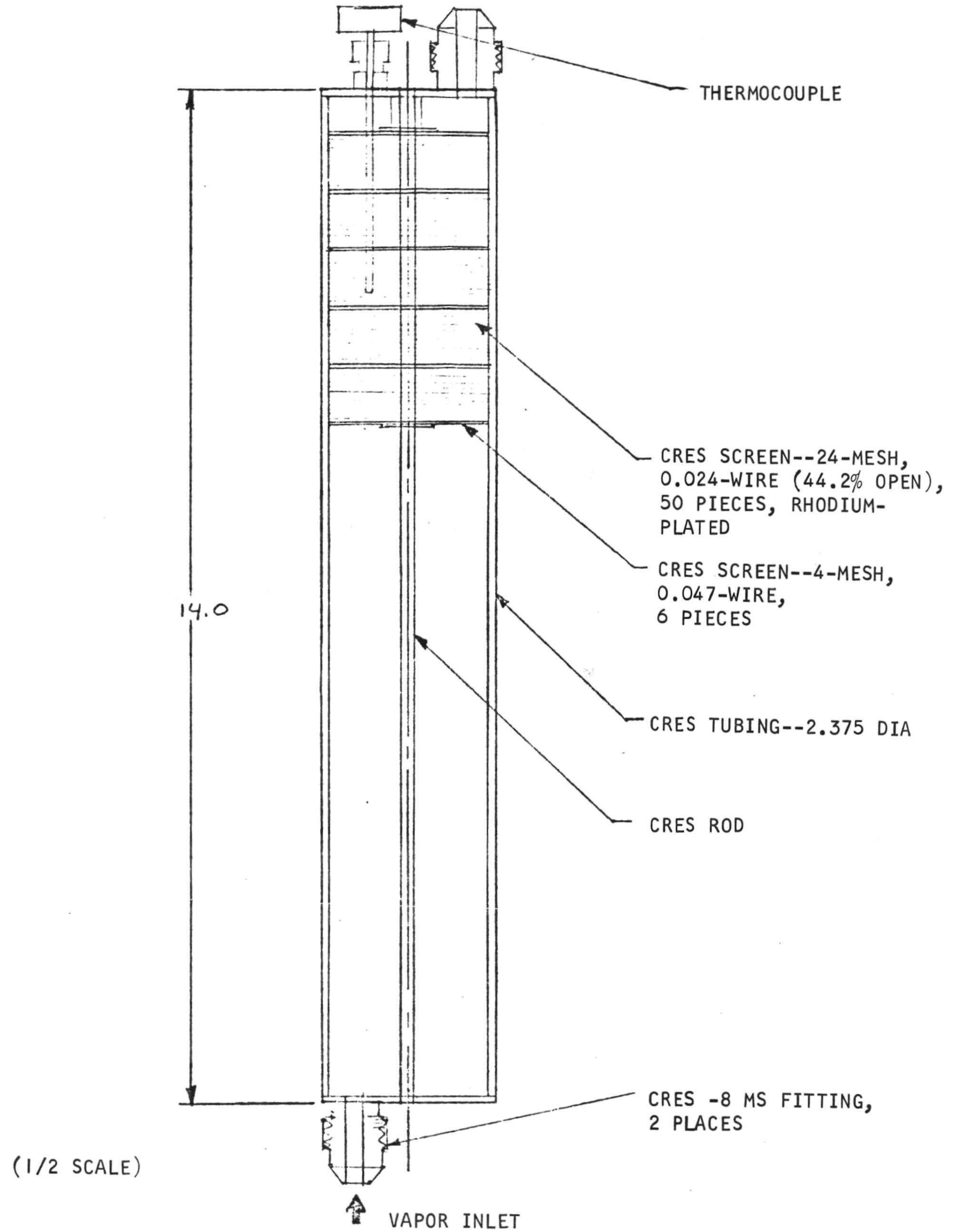
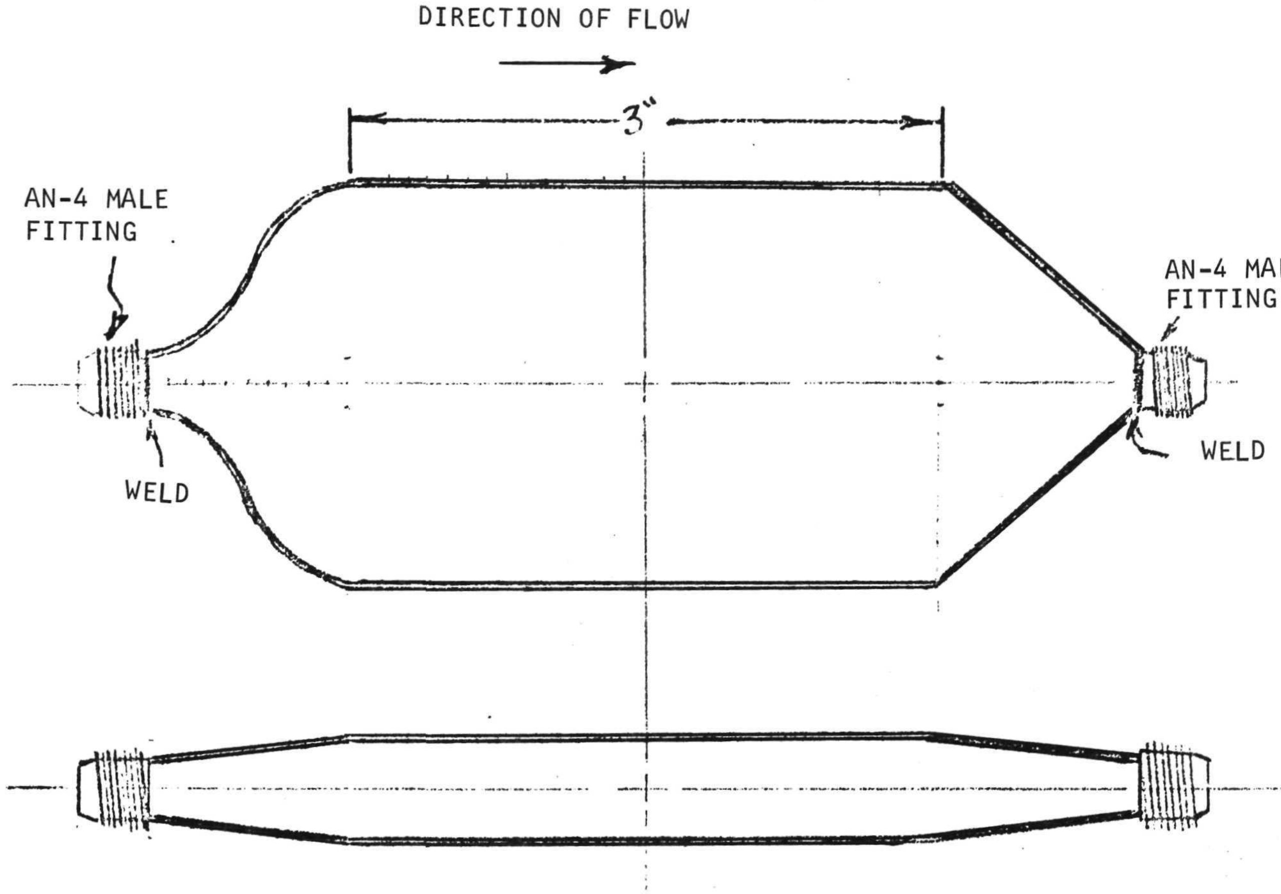


Figure 3-14. Pyrolysis Reactor Construction



MATERIAL: TYPE-304 CRES SHEET, 0.020 THICK

(FULL SCALE)

Figure 3-15. Density Sensor Cavity Shell

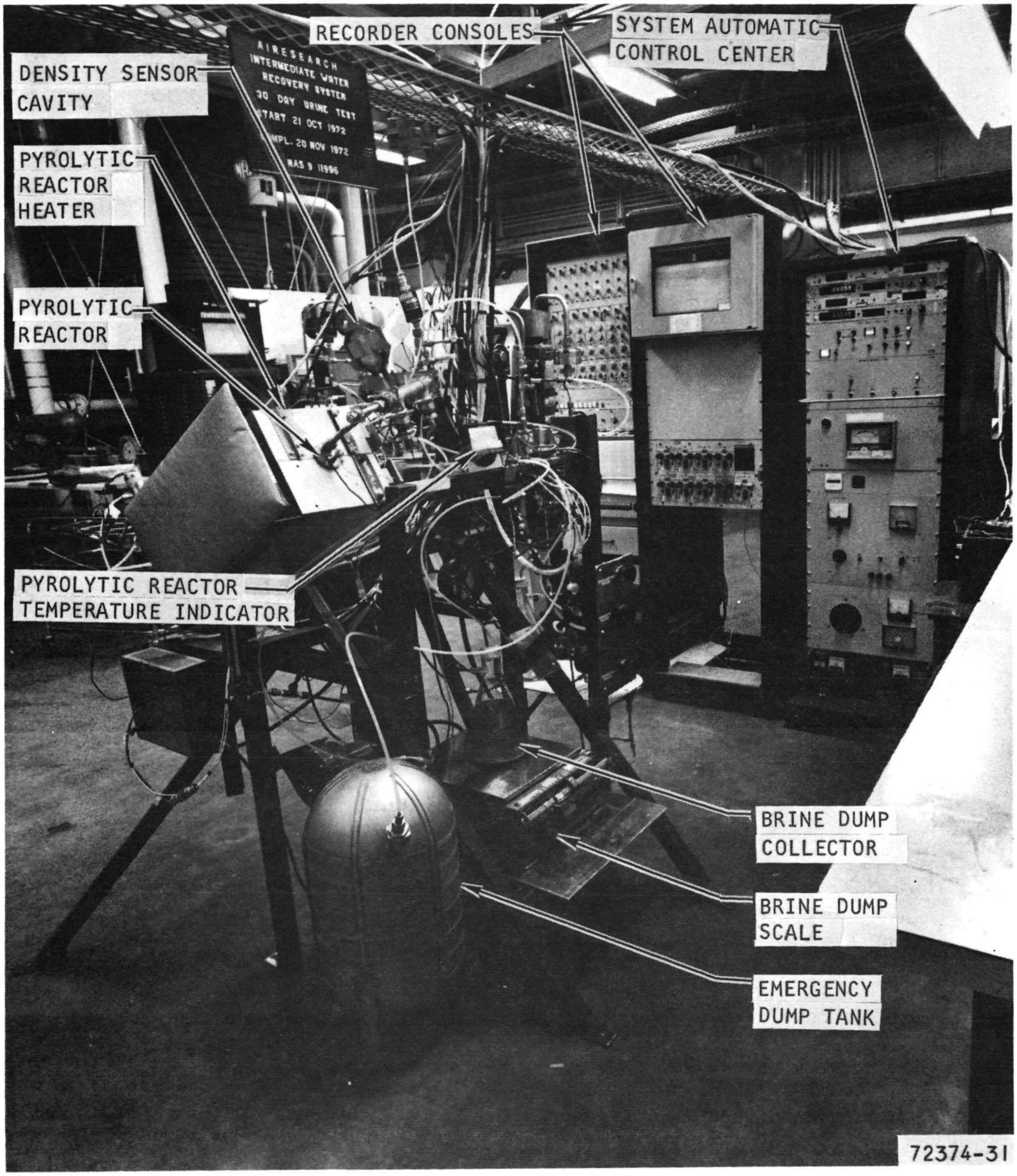


Figure 3-16. Test Setup

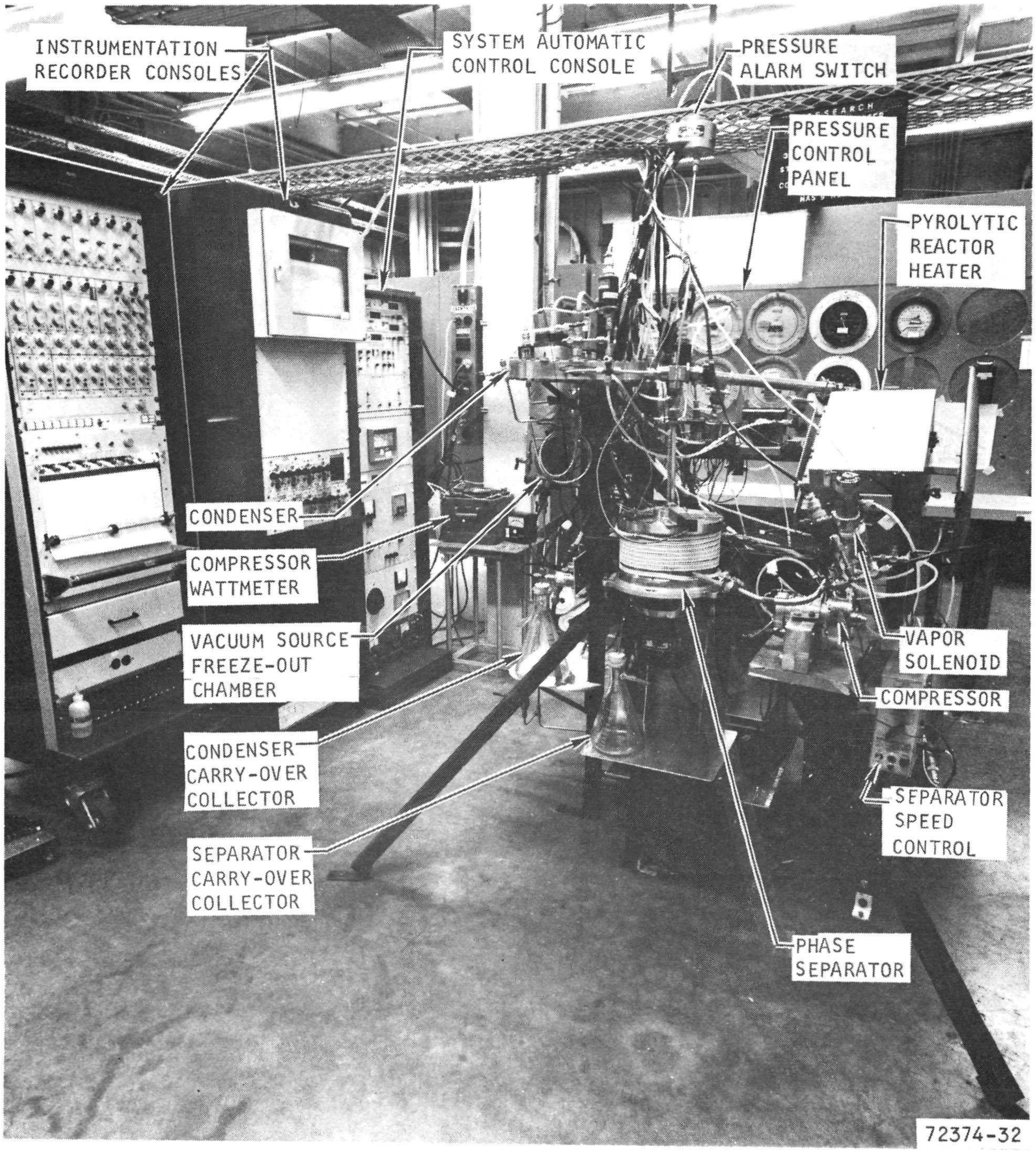


Figure 3-17. IWRS Test Setup

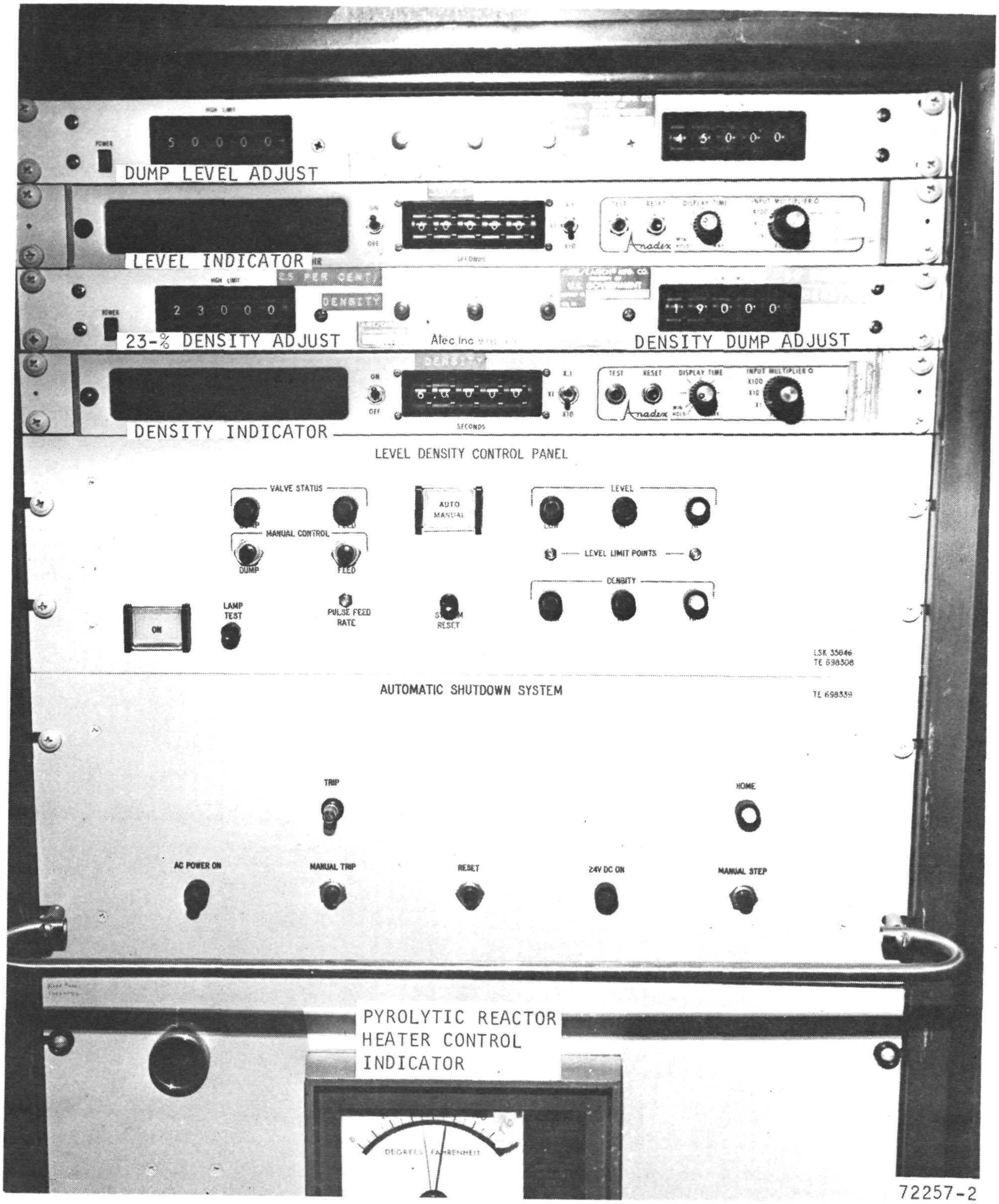


Figure 3-18. Control Console

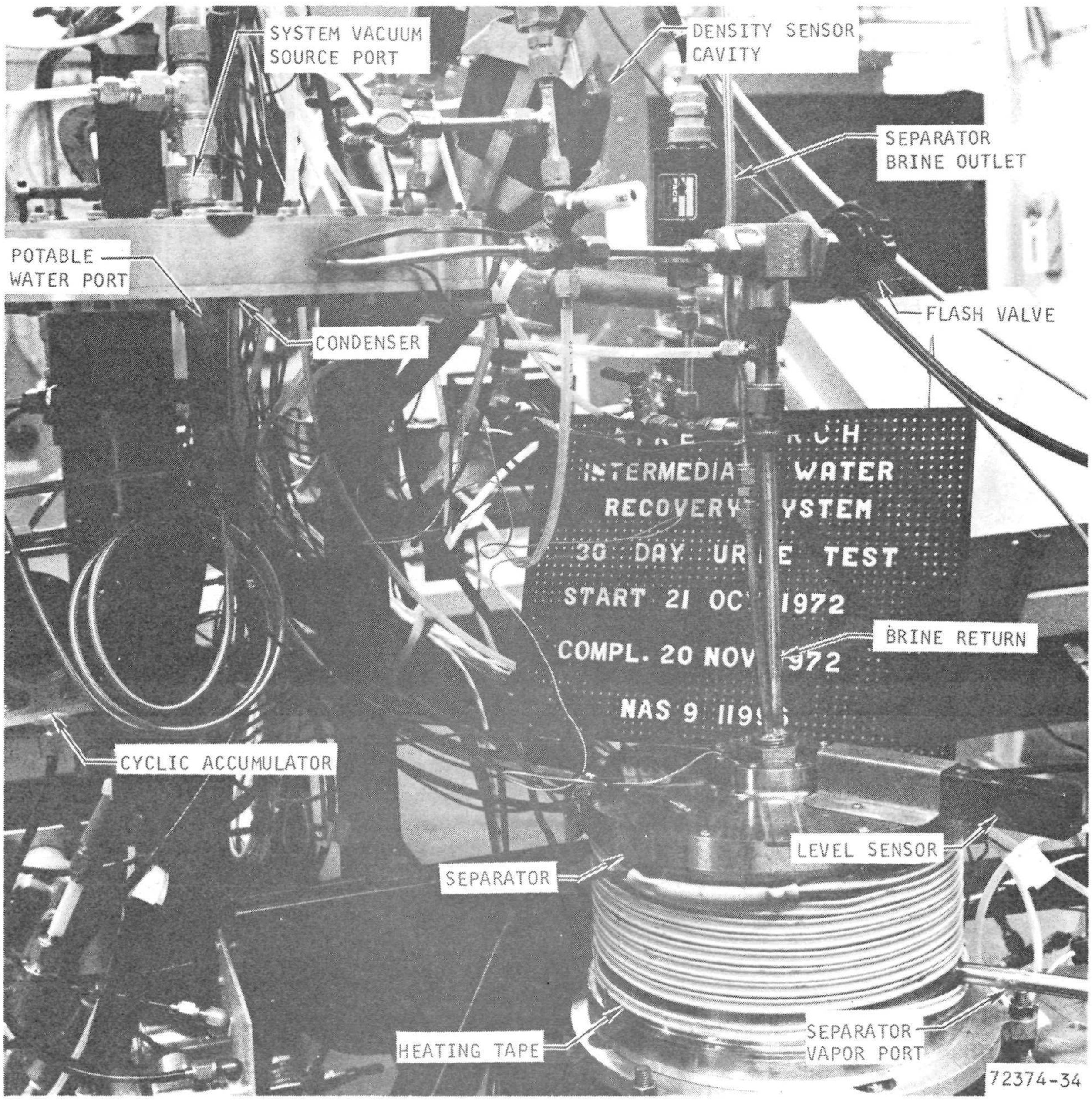


Figure 3-19. IWRS Test Setup

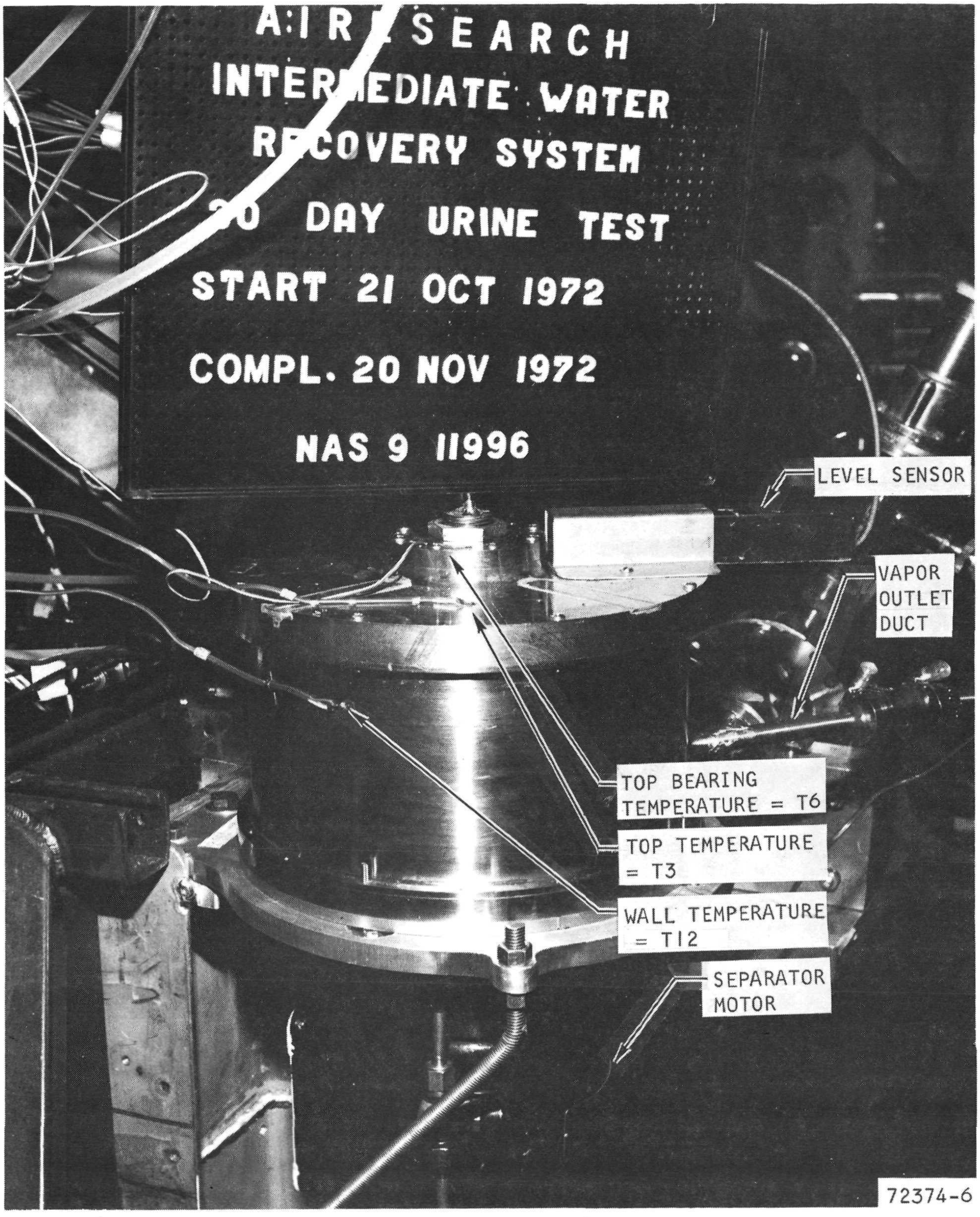


Figure 3-20. IWRS Test Setup

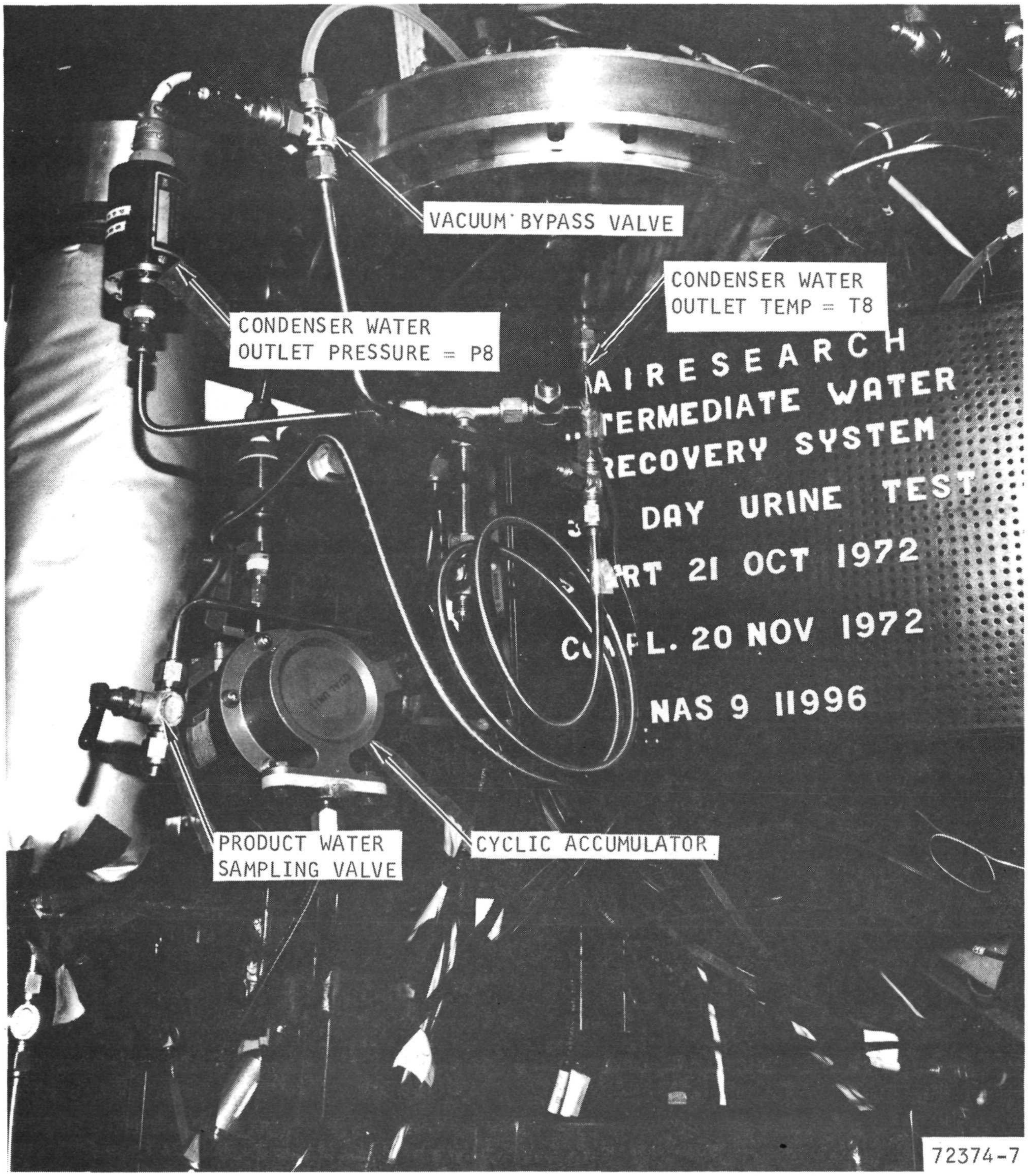


Figure 3-21. IWRS Test Setup

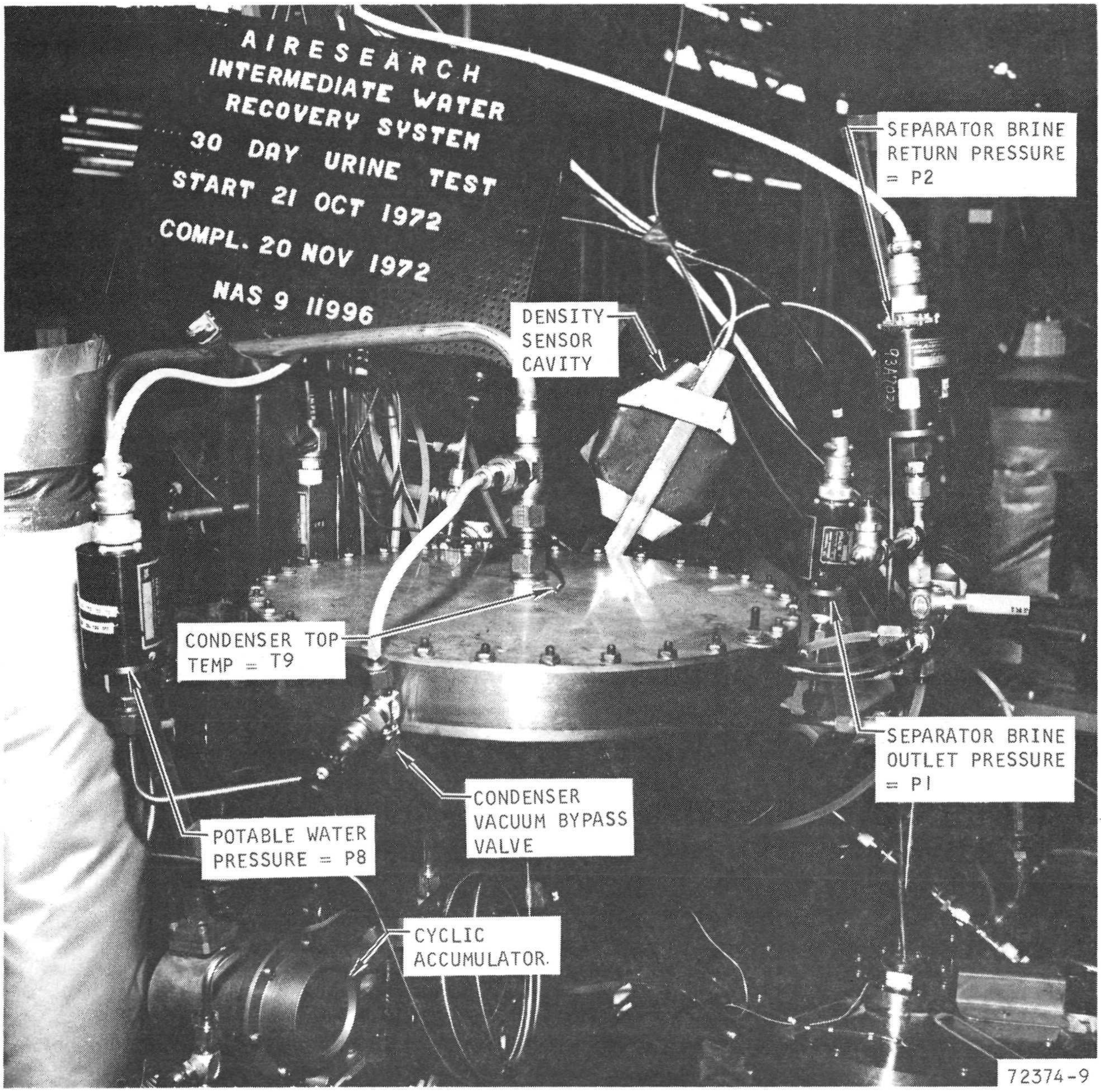


Figure 3-22. IWRS Test Setup

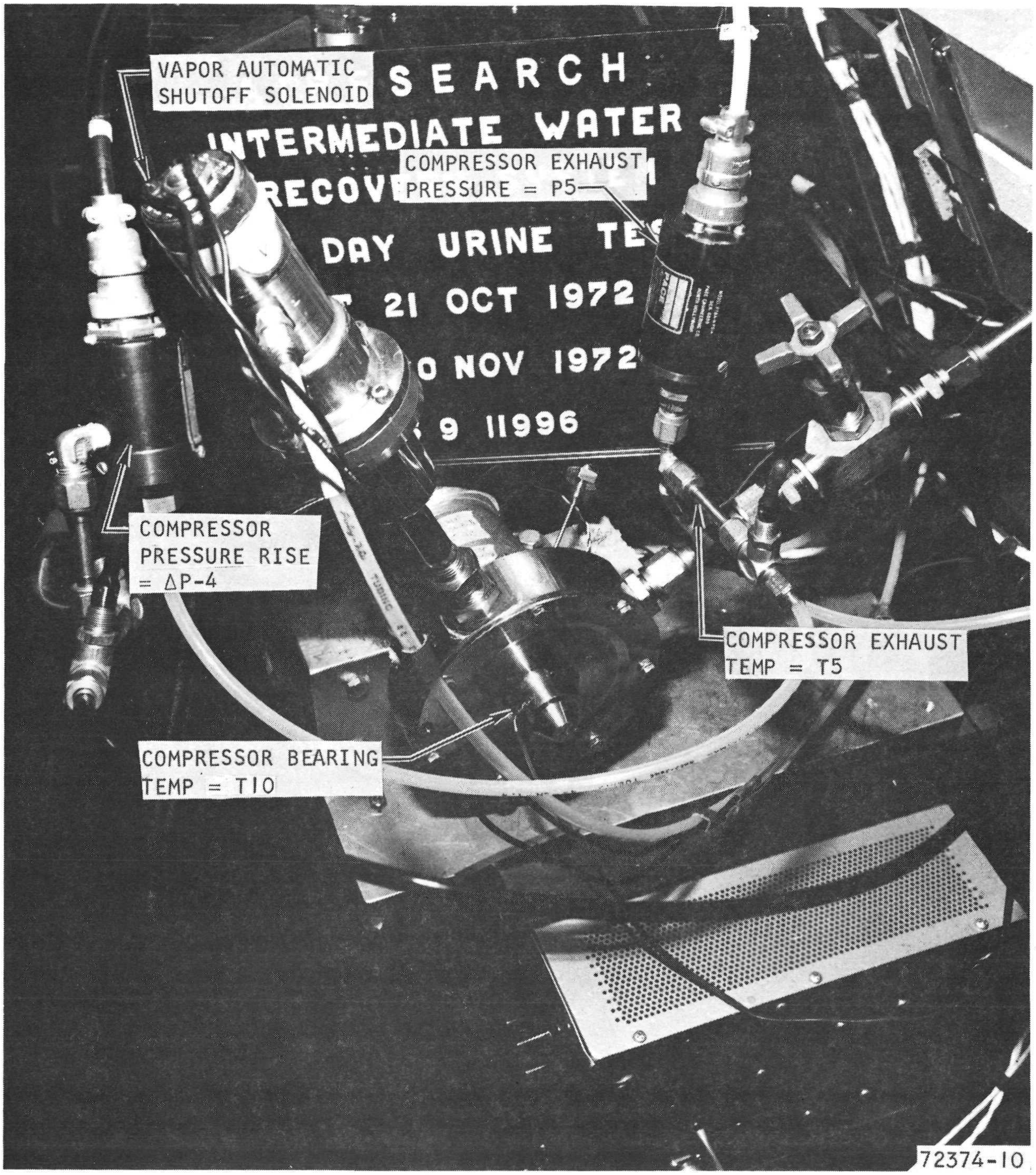


Figure 3-23. Vortex Compressor

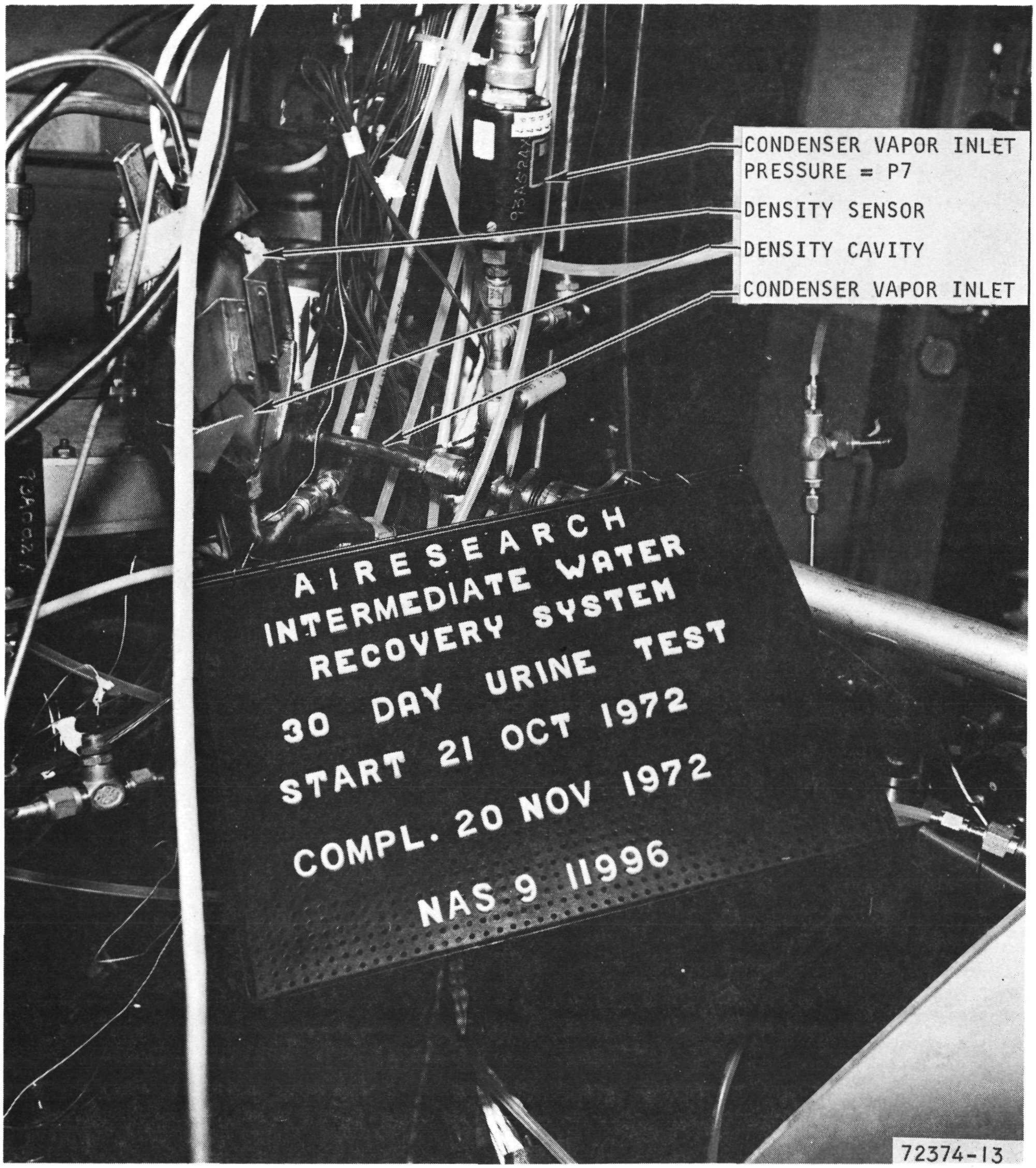


Figure 3-24. Density Sensor Cavity

Figure 3-25. Pyrolysis Reactor and Heater

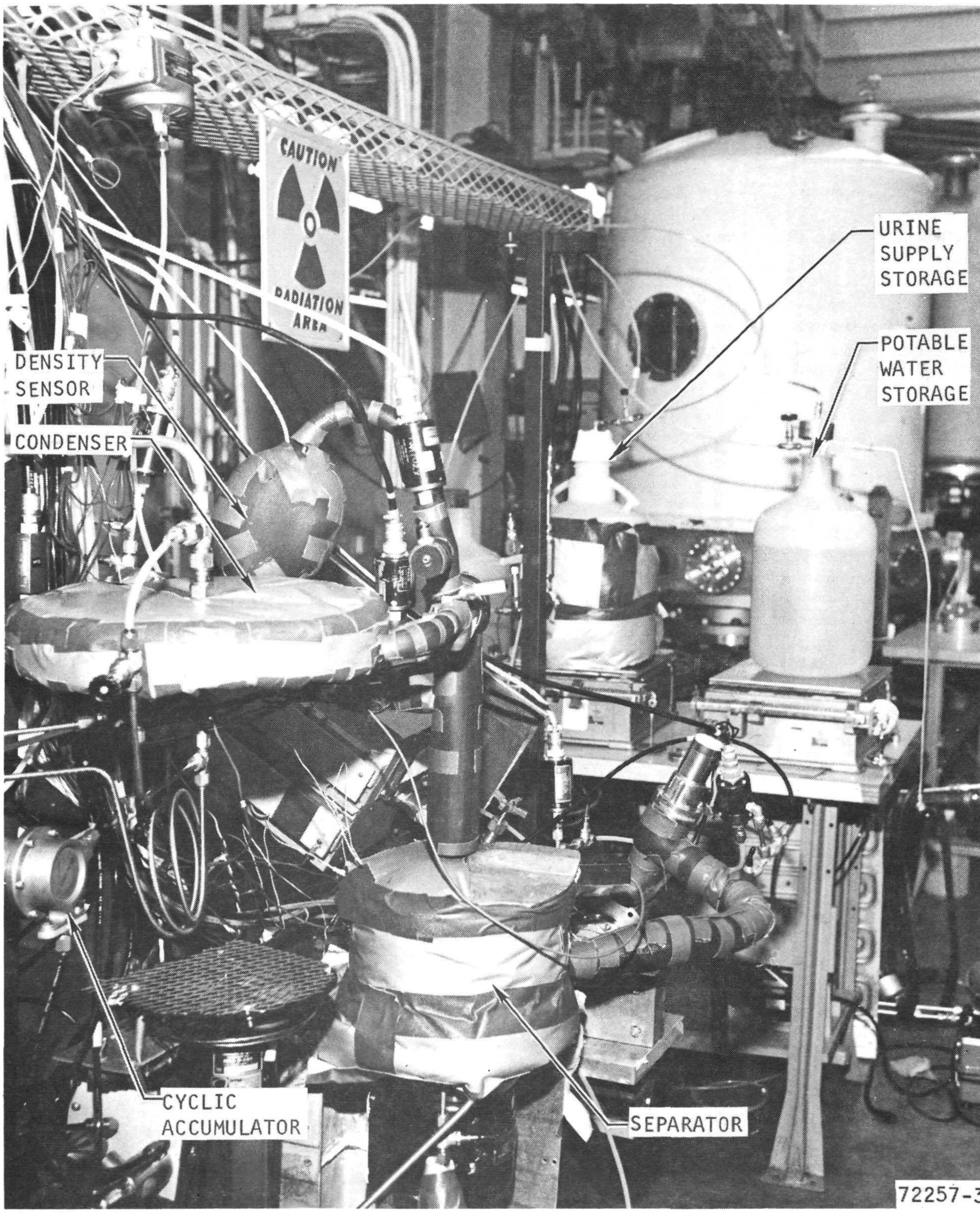


Figure 3-26. IWRS Overall Test Setup

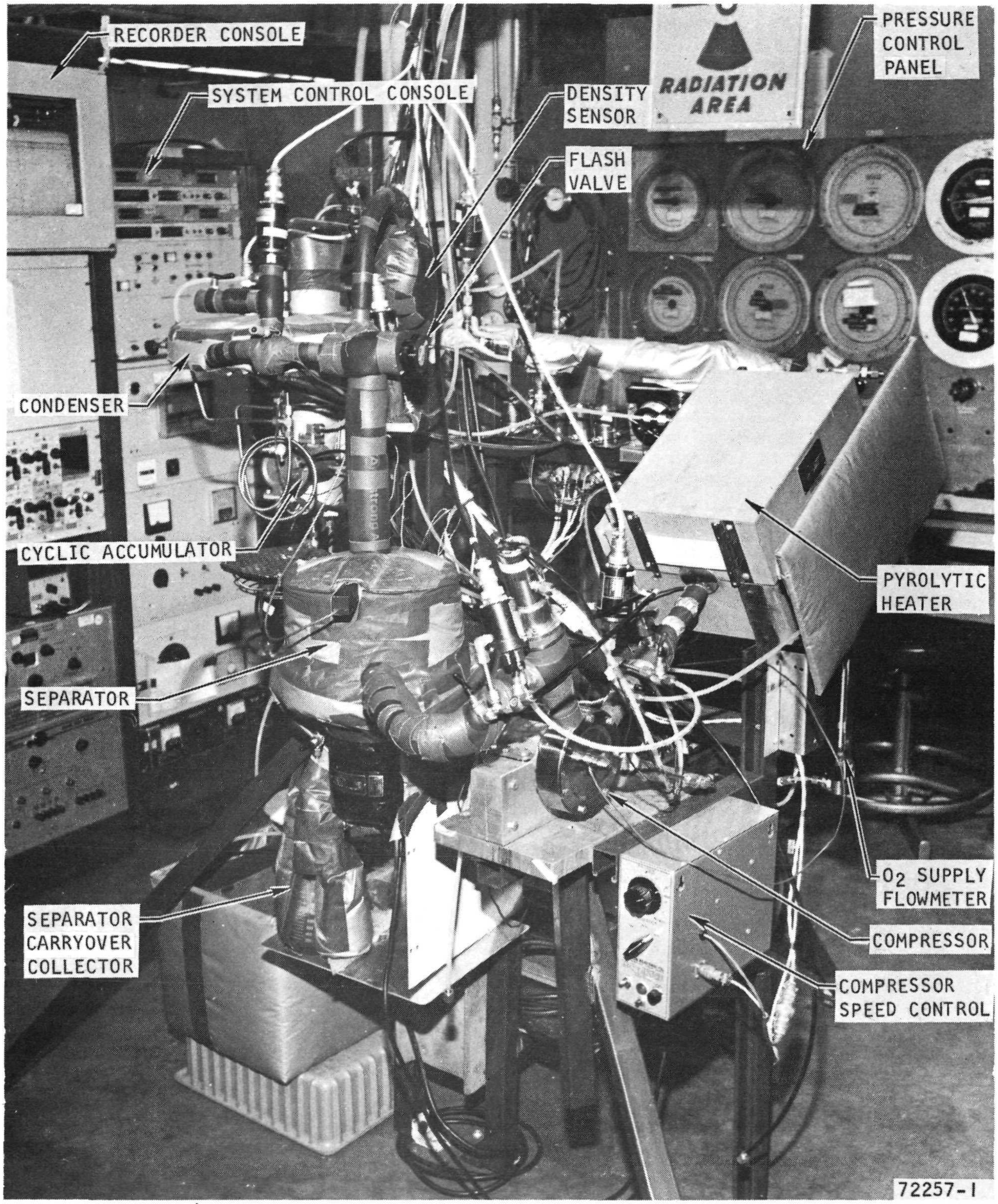


Figure 3-27. IWRS Overall Test Setup

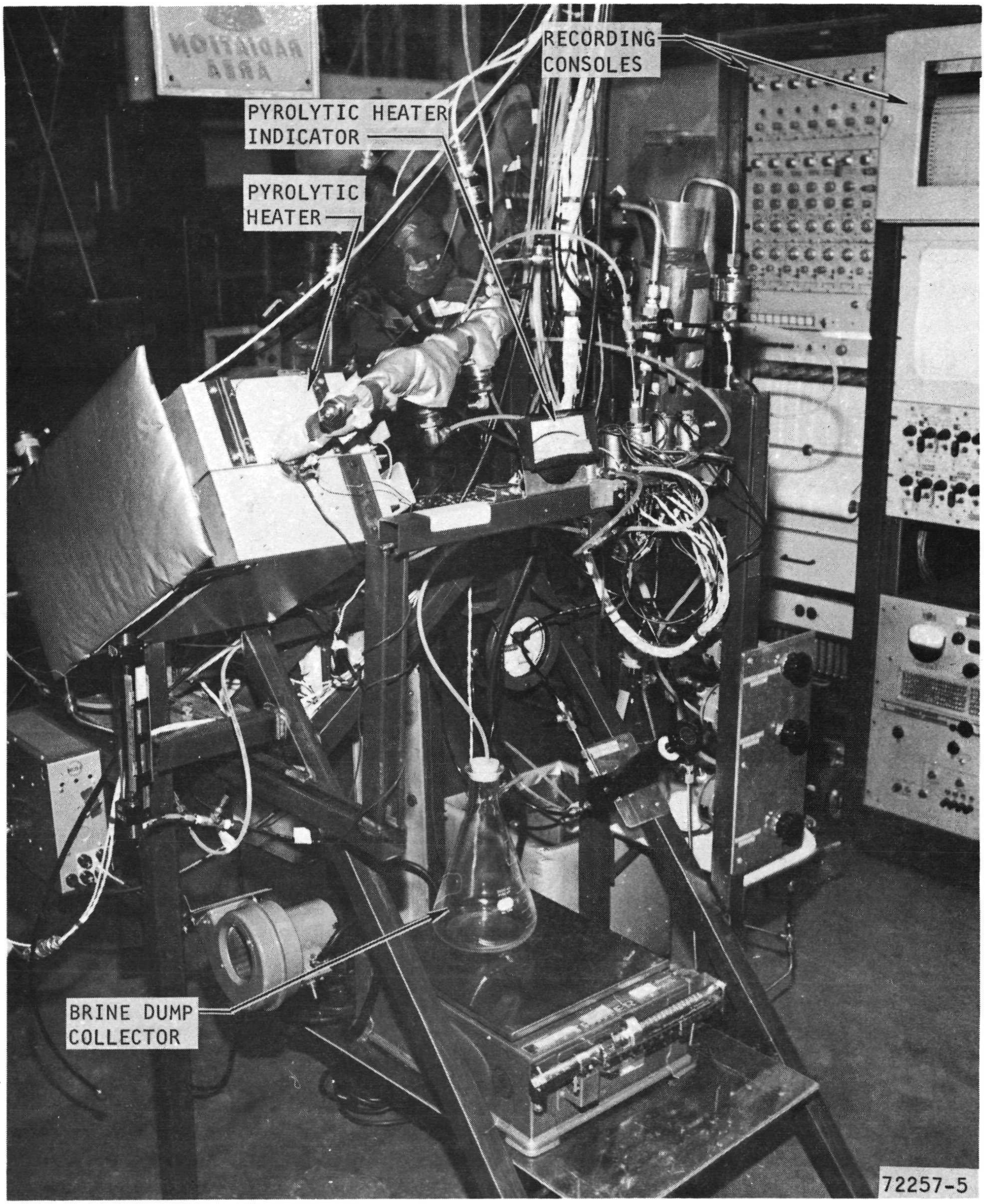


Figure 3-28. IWRS Overall Test Setup

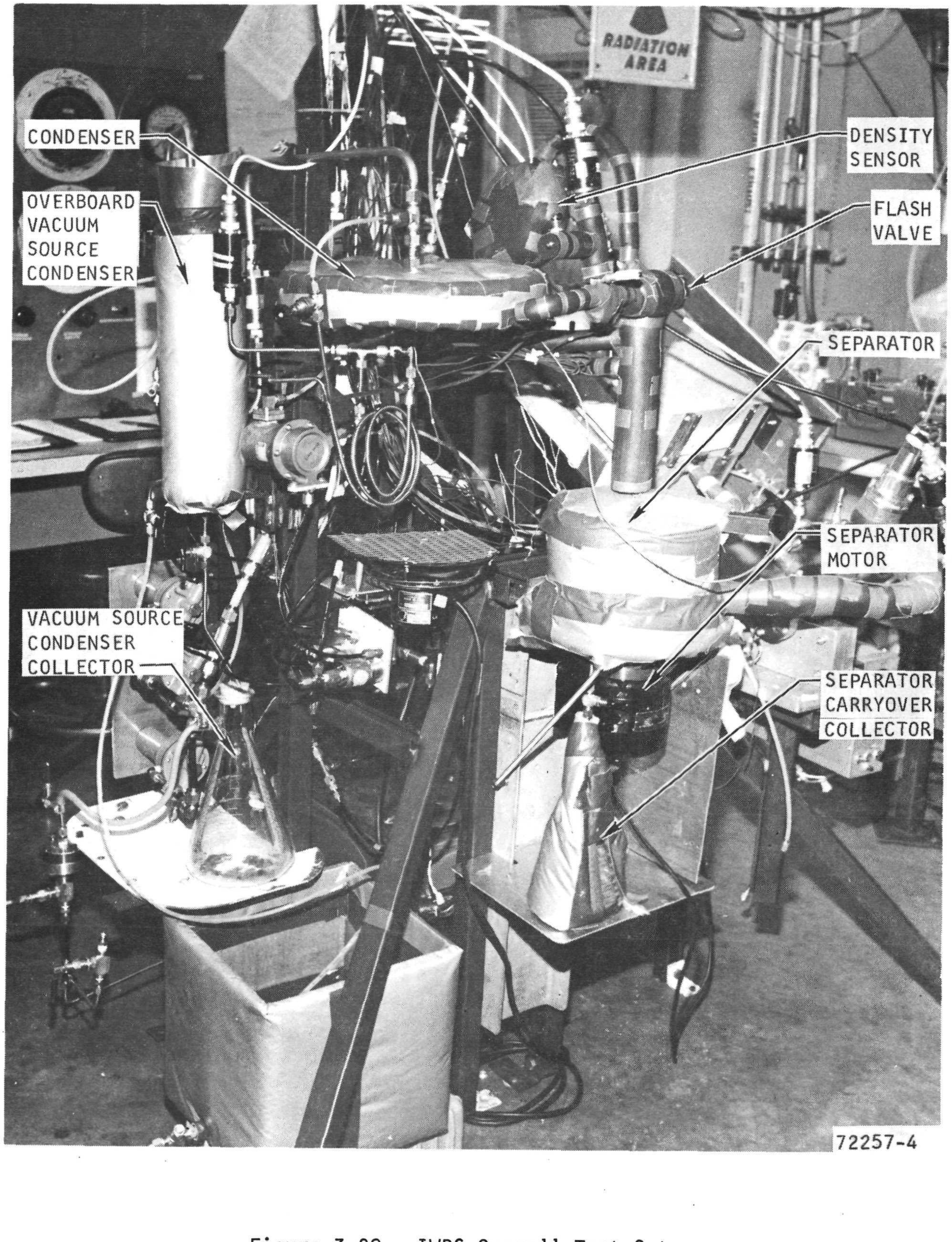


Figure 3-29. IWRS Overall Test Setup

30-Day Test With Urine

System checkout in accordance with procedures used for previous tests was completed 18 October 1972. The separator urine level sensor response was determined for system control calibration; the sensor calibration curve is shown on Figure 3-30. After system checkout was completed, the system was sterilized by autoclaving the vapor and water loop downstream of the pyrolysis reactor and started up with deionized water. Switchover from deionized water to urine occurred at 0010 hour on 21 October 1972. Urine used for the test was initially pretreated with 1.3 percent Chemtric solution.

The initial brine loop flow rate was 195 lb/hr. The flow rate thereafter was dependent on the extent of salt buildup in the loop. During the first system cycle, density sensor response to various urine-brine concentrations was recorded to calibrate the control system. The density sensor calibration curve is shown on Figure 3-31. Typical system performance for the first cycle is shown on Figure 3-32.

Product water samples were taken for microbiological analysis. One sample for baseline data was taken prior to initiation of urine into the system. The second sample was taken 16 hours after the start of system operation with urine. No microorganisms were found in the product water (see appendix to this report). Daily samples of product water were checked for odor. The percentages and accumulative total of urine feed and product water recovered from the urine feed are plotted on Figure 3-33.

A total of 26 water recovery cycles were performed on the IWRS in the 30-day test period. Performance data for each cycle is shown on Table 3-2. Cycles 11 and 15 were aborted to flush the brine loop with water. Cycle 17 was aborted to reset the fluid density control.

The time to complete a cycle ranged from 16-1/2 to 61 hours. With the system properly calibrated and running smoothly, the time to complete a cycle averaged 27 hours. Cycle 1, which was started with residual water in the brine loop, as a result of switching from water to urine, was the longest cycle. The two other long cycles (12 and 16) also were started with residual water in the brine loop, as a result of flushing to remove salt deposits. Cycle 22, which was shortened because of improper setting of the density control, which caused premature dumping, was the shortest cycle. Other pertinent test results are summarized below.

Daily Product Water Average Flow Rate	0.32 to 0.90 lb/hr (0.48 avg)
Solids Content of Dumped Brine	31 to 64 percent (50 avg)
Separator Speed (First 14 cycles)	960 to 1120 rpm
Separator Speed (Last 10 cycles)	1490 to 1715 rpm
Compressor Inlet Pressure	0.6 to 0.8 psia

NOTE:

ZERO QUANTITY IN SEPARATOR REPRESENTS LEVEL AFTER MAX. DUMP CYCLE

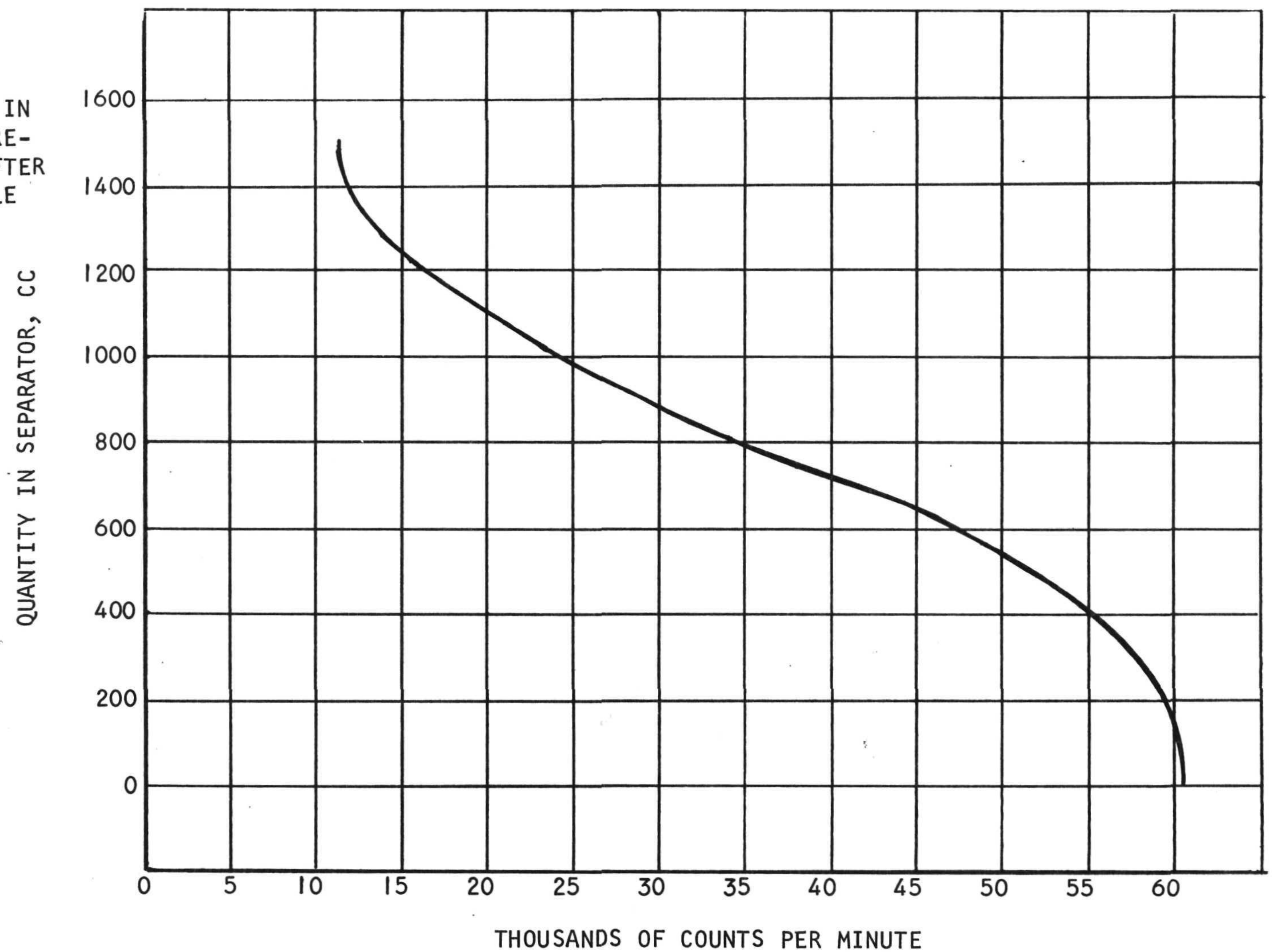


Figure 3-30. Level Sensor Calibration with Water

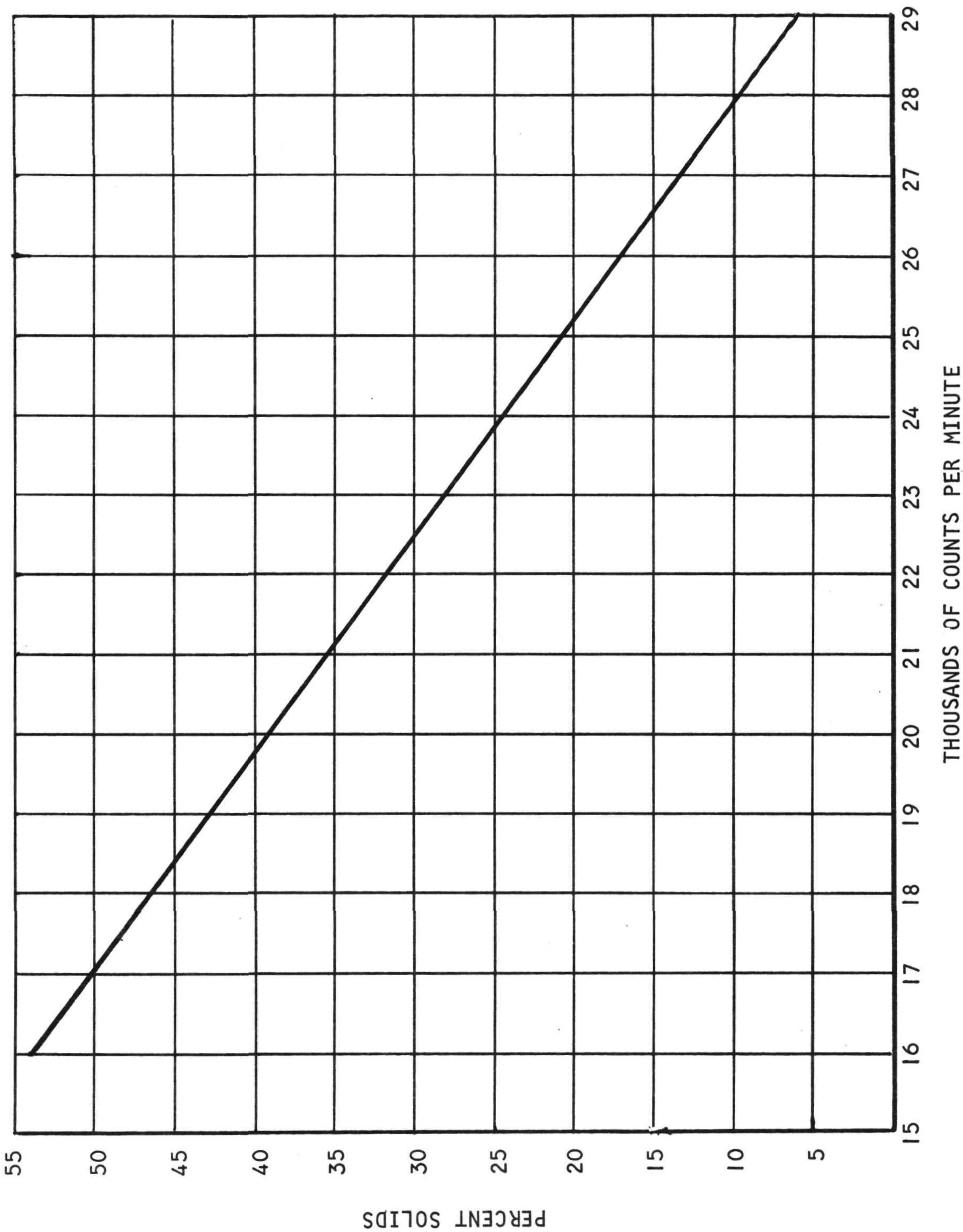


Figure 3-31. Density Sensor Calibration with Water

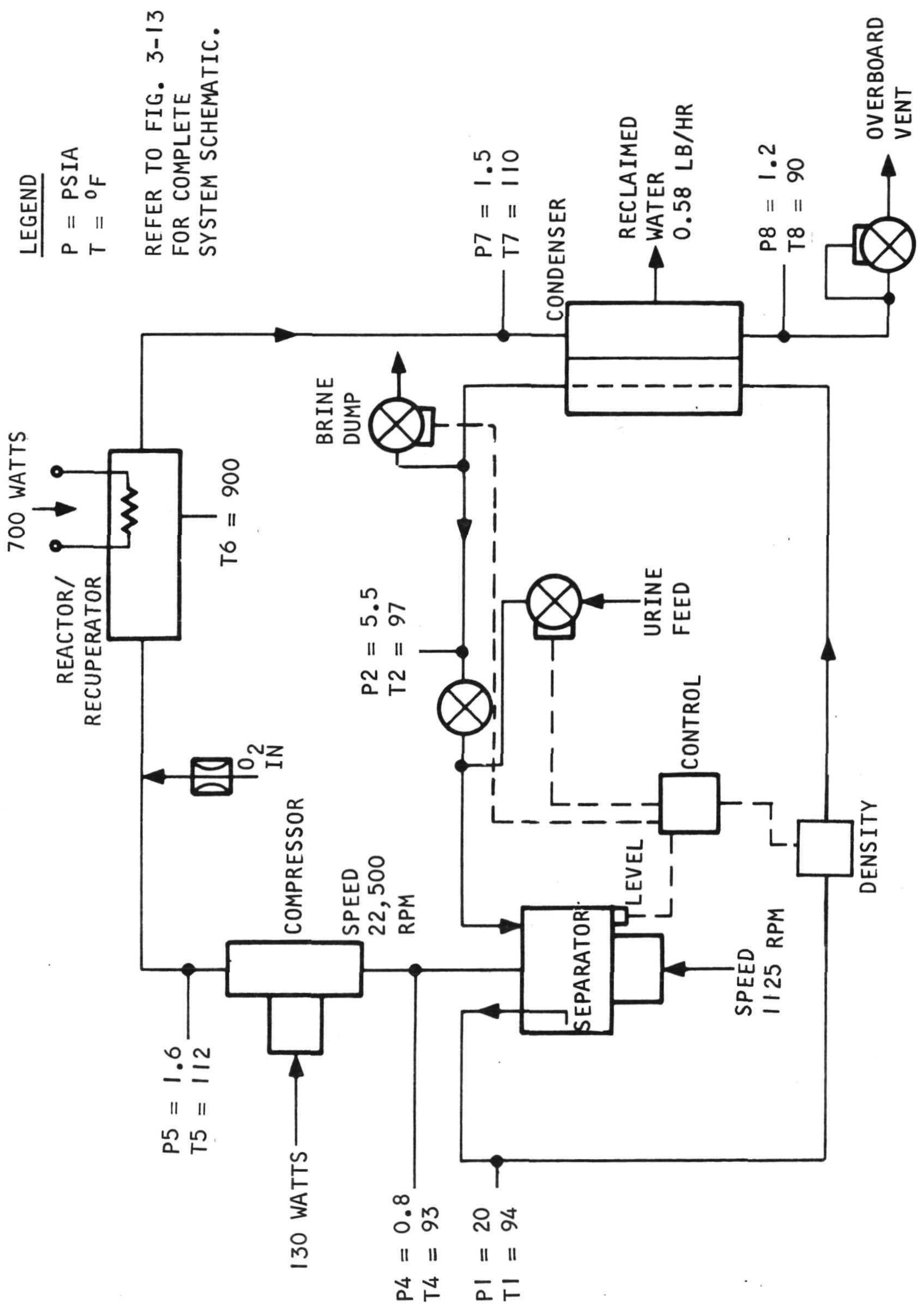


Figure 3-32. Typical System Performance--30-Day Breadboard Test

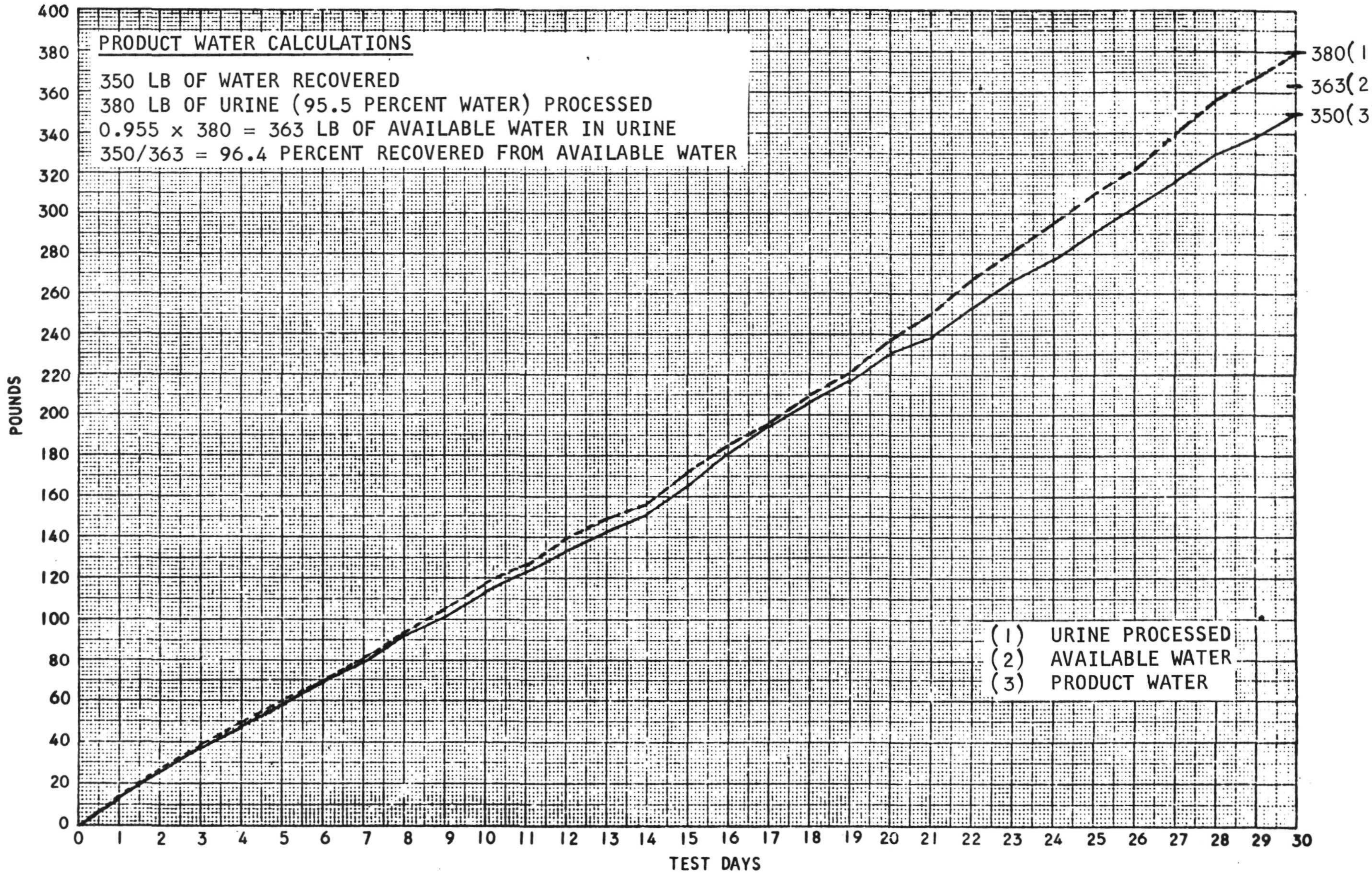


Figure 3-33. Accumulated Urine Feed and Product Water

TABLE 3-2

IWRS PERFORMANCE DURING 30-DAY CONTINUOUS TEST

SYSTEM CYCLE	NO.	1	2	3	4	5	6	7	8	9	10**	11 (a)	12	13	14	15 (a)
CYCLE START DATE/HOUR	Mo-day/hr	10-21/0010	10-23/1500	10-24/1200	10-25/0600	10-26/1000	10-27/0900	10-28/1200	10-29/1200	10-30/1700	11-1/0000	11-2/1030	11-5/1300	11-5/2100	11-6/2400	11-6/0445
TEST DAY	NO.	1	3	4	5	6	7	8	9	10	12	13	16	16	18	19
SYSTEM CYCLE LENGTH	Hours	61	21	18	28	23	24	24	29	31	34	--	52	27	28	--
PRODUCT WATER SAMPLE WEIGHT	Lbs.	***	***	***	***	0.47	0.40	0.44	0.24	0.35	0.38	0.36	0.39	0.36	0.51	***
PRODUCT WATER CONDUCTIVITY	mm/cm	***	***	***	***	125	155	135.	115	120	120	135	200	185	184	***
PRODUCT WATER pH	pH	***	***	***	***	8.3	7.7	7.35	7.4	7.3	7.24	7.20	7.5	7.5	7.2	***
PRODUCT WATER AVERAGE FLOW	Lb/Hr	0.51	0.45	0.43	0.45	0.48	0.47	0.56	0.49	0.46	0.43	0.37	0.46	0.56	0.44	0.32
PHASE SEPARATOR - Brine Out Temp T1	°F	94.0	93.5	94.0	94.0	94.0	94.5	94.5	94.0	93.0	91.0	94.5	94.0	94.0	92.5	93.0
- Brine Return Temp T2	°F	98.3	97.5	97.5	98.0	98.0	98.0	97.5	97.0	95.5	93.0	97.0	97.0	97.0	95.0	91.0
- Brine Out Press P1	Psia	15.0	13.2	13.8	14.0	14.0	13.7	13.3	13.5	12.7	15.7	20.2	20.0	20.3	21.0	25.0
- Brine Return Press P2	Psia	10.05	4.0	5.0	5.0	5.0	4.7	5.3	5.0	6.0	5.5	5.5	5.1	5.3	4.5	2.7
- Wall Temp T12	°F	119.0	117.5	117.0	118.0	118.5	118.0	119.0	119.0	117.0	116.5	120.0	119.0	118.5	118.0	119.0
- Top Temp T3	°F	112.0	110.5	111.0	111.5	111.5	111.0	112.0	112.0	111.0	110.0	113.5	113.0	112.5	111.5	113.0
- Bearing Temp T6	°F	106.0	105.0	105.5	106.0	107.0	107.0	109.0	109.0	109.0	107.0	105.0	106.0	104.5	104.0	106.0
- Flash Valve Turns Open		3/4	3/4	3/4	1	1	1	1	1	1	1	1	1	1-1/2	1-1/2	1-1/2
- Speed	RPM.	1020	1020	1020	1020	1020	1020/270	1020	1020	1020	960	1125	1120	1120	1115	1110
COMPRESSOR - Vapor In Press P4	Psia	***	***	***	***	***	0.66	0.76	0.70	0.74	0.72	0.73	0.72	0.76	0.62	0.63
- Vapor In Temp T4	°F	94.5	94.0	93.0	94.0	91.0	94.0	94.5	94.0	92.0	90.0	93.0	92.0	93.0	92.5	85.0
- Pressure Rise ΔP	Psi	0.70	0.90	0.80	0.57	0.80	0.74	0.78	0.8	0.95	0.25	0.52	0.52	0.33	0.70	0.70
- Vapor Out Temp T5	°F	113.0	112.0	112.0	112.5	112.0	113.0	113.5	113.0	112.0	112.0	111.5	112.0	111.5	111.5	85
- Vapor Out Press P5	Psia	1.00	1.07	1.04	1.03	1.00	1.10	1.20	1.70	1.15	1.30	1.10	1.12	1.10	1.10	1.00
- Bearing Temp T10	°F	138	134	135	135	136	120	121	122	124	124	121	120	122	122	123.5
- Motor Bearing Temp T11	°F	130	120	120	121	122	135	136	139	116	126	118	118	118.5	122.5	119
- Speed/Power	Hz/Watts	1124/130	1124/130	1124/130	1128/13[illegible]	128/132	1125/135	1125/138	1134/138	1117/143	1123/139	1136/122	1137/122	1136/122	1136/122	1139/125
PYROLYTIC REACTOR BED TEMPERATURE	°F	780	780	780	890	890	880	900	870	885	880	930	925	900	890	880
CONDENSER - Inlet Temp T7	°F	110	112	111.5	112	112	112	113	112	112	112	110	111	110	110	110
- Inlet Press P7	Psia	1.49	1.55	1.50	1.49	1.48	1.48	1.51	1.48	1.48	1.42	1.54	1.50	1.55	1.57	1.55
- Out Temp T9	°F	97.5	96.5	96.5	97.0	98.0	99.0	98.0	99.0	98.5	95.0	107.0	105.0	107.5	106.5	93.0
- Out Press P14	Psia	1.5	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
- Overboard Press P12	Psia	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6	1.54	1.55	1.54	1.53	1.53
- Flow Meter ΔP	in H20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- Water Out Temp T8	°F	90.5	87.8	88.0	88.5	88.0	90.0	89.5	90.0	90.0	91.0	94.0	94.5	92.0	91.5	89.0
- Water Out Press P8	Psia	0.85	0.85	0.94	0.09	0.09	0.09	0.09	0.95	0.75	0.85	0.75	0.75	0.75	0.75	0.75
ACCUMULATOR - N_2 Exp Press P9	Psia	34.0	34.0	34.0	34.1	34.0	34.0	34.0	34.0	34.1	34.1	34.0	34.1	34.0	34.0	34.0
- Vent Back Press P15	Psia	1.40	1.40	1.40	1.40	1.40	1.42	1.40	1.40	1.39	1.38	1.30	1.40	1.10	0.70	1.30
URINE FEED - Average Flow Rate	Lb/Hr	0.475	0.38	0.50	0.45	0.46	0.48	0.52	0.51	0.40	0.44	***	0.52	0.47	0.45	0.32
BRINE DUMP - Weight	Lbs	Est. 2.3	0.4	0.71	0.5	0.55	0.68	0.61	0.70	1.13	2.48	***	1.14	0.87	***	0.60
- Percent Solids	%	55.7	55	55	58	58.5	55.0	57.0	53.0	53.6	31.0	***	55.6	58	***	64
LEVEL Counts at Brine Dump	Count/Min	58383	54620	51128	52676	50846	45626	47313	42228	42211	43449	***	42668	45566	***	51548
DENSITY Counts at Brine Dump	Count/Min	15728	15936	16998	16877	17990	18955	18856	19943	19981	13867	***	20024	20257	***	20250

*Data during steady-state pulse feeding.

**Manual dump.

***Data not available.

(a) Cycles 11 15 were aborted to flush brine loop with water. Because of this, cycles 12 and 16 were started with low density brine in the loop, causing long - duration cycles.

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TABLE 3-2 (Continued)

SYSTEM CYCLE	NO.	16	17 (a)	18	19	20	21	22	23	24	25	26
CYCLE START DATE/HOUR	Mo-day/hr	11-8/1700	11-10/0500	11-10/1500	11-11/1800	11-13/0300	11-14/1800	11-16/0600	11-16/2300	11-17/2000	11-18/2330	11-20/0200
TEST DAY	NO.	19	21	21	22	24	25	27	27	28	29	31
SYSTEM CYCLE LENGTH	Hours	36	--	27	33	39	34	16-1/2	21-1/2	27-1/2	26-1/2	NOT COMPLETED
PRODUCT WATER SAMPLE WEIGHT	Lbs.	0.47	**	0.42	0.47	0.44	0.40	1.59	0.44	0.53	0.31	**
PRODUCT WATER CONDUCTIVITY	mm/cm	650	**	1000	740	650	600	390	600	510	690	800
PRODUCT WATER pH	pH	8.0	**	9.3	9.25	9.1	9.22	9.34	9.45	9.35	9.3	9.35
PRODUCT WATER AVERAGE FLOW	Lb/Hr	0.90	0.35	0.72	0.58	0.53	0.51	0.66	0.63	0.51	0.53	0.28
PHASE SEPARATOR - Brine Out Temp T1	°F	90	86.5	87	87	88	88	94	94	91	90.5	88.5
- Brine Return Temp T2	°F	101	94.5	99	97	97.5	98.5	104.5	105	99	98	95
- Brine Out Press P1	Psia	18.5	16.0	14.7	14.7	14.7	15.0	21.3	21.0	17.5	17.0	16.0
- Brine Return Press P2	Psia	3.5	3.5	2.7	2.7	2.7	2.5	2.7	2.5	2.2	2.5	2.5
- Wall Temp T12	°F	121	117.5	118.5	118.5	117	118	122	122	119	119	116
- Top Temp T3	°F	116	111.5	112	110.5	110	111	115.5	115.5	112	111	109
- Bearing Temp T6	°F	98.5	105	104.5	98.5	99.5	100	106.5	106	102.5	102	99
- Flash Valve Turns Open		1-3/4	1-3/4	2	2	2	2-1/4	3	3	3	3	3
- Speed	RPM	1120	1500	1490	1500	490	1470	1715	1700	1500	1495	1490
COMPRESSOR - Vapor In Press P4	Psia	0.76		0.8	0.78	0.66	0.60	0.75	0.74	0.68	0.70	0.71
- Vapor In Temp T4	°F	96	87	94.5	94	94	99	99	99	94	94	91
- Pressure Rise ΔP	Psi	0.60	0.34	0.6	0.6	0.67	0.63	0.5	0.42	0.5	0.48	0.60
- Vapor Out Temp T5	°F	114	111	112	111	112	112.5	115	114	112.5	111	112.5
- Vapor Out Press P5	Psia	1.2	1.07	1.6	1.2	1.22	1.20	1.25	1.75	1.75	1.65	1.25
- Bearing Temp T10	°F	120.5	124	121	119	120	122	120.5	119	122	121	122
- Motor Bearing Temp T11	°F	113	116.5	114.5	112.5	114	116	114	114	116.5	117	116
- Speed/Power	Hz/Watts	1135/126	1135/126	1135/128	1136/125	1135/128	1135/124	1135/126	1131/130	1134/126	1138/122	1131/130
PYROLYTIC REACTOR BED TEMPERATURE	°F	900	900	900	900	860	865	870	870	890	890	875
CONDENSER - Inlet Temp T7	°F	107	107	107	106	110.5	111	112	132	112	110	112.5
- Inlet Press P7	Psia	1.55	1.50	1.32	1.42	1.42	1.35	1.4	1.5	1.5	1.2	1.65
- Out Temp T9	°F	107	92.3	101	102	102	103	111	110	99	100	91
- Out Press P14	Psia	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
- Overboard Press P12	Psia	1.53	1.52	1.52	1.47	1.45	1.45	1.45	1.45	1.45	1.38	1.38
- Flow Meter ΔP	in.H20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- Water Out Temp T8	°F	94	88.5	91.5	91	90	91	94	88	88.5	86	82
- Water Out Press P8	Psia	0.07	0.07	0.07	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
ACCUMULATOR - N_2 Exp Press P9	Psia	34.1	**	33.9	34.0	34.0	34.0	33.9	33.9	34.0	34.05	34.05
- Vent Back Press P15	Psia	1.3	**	0.4	0.4	0.6	0.4	0.7	0.6	0.7	0.4	0.75
URINE FEED - Average Flow Rate	Lb/Hr	0.91	**	0.80	0.59	0.58	0.48	0.73	0.63	0.475	0.546	**
BRINE DUMP - Weight	Lbs	0.68	**	2.13	1.92	1.33	0.74	1.01	0.85	0.99	0.83	**
- Percent Solids	%	61	30	32	30	36.2	42.2	47.4	49.0	47.4	49.6	**
LEVEL Counts at Brine Dump	Count/Min	47418	48369	32066	33408	33416	45791	48550	49172	45800	50244	**
DENSITY Counts at Brine Dump	Count/Min	20260	23038	23085	22845	22291	20488	19913	19985	21055	19940	**

*Data during steady-state pulse feeding.

** Data not available.

(a) Cycle 17 was aborted to reset density control.

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The water production rate for the first cycle was 0.51 lb/hr at a phase separator speed of 1020 rpm. The separator was designed to operate at 2200 rpm, but during system checkout, separator speeds above 1125 rpm caused fluctuations in brine outlet pressure (P1) and brine return pressure (P2), indicating some disturbance around the pitot tube. Higher separator speeds produced a "rooster tail" effect on the pitot tube which could cause excessive turbulence within the separator bowl, which, in turn, would result in brine carryover into the vapor loop.

The product water from the first cycle had a mild musty odor. After the water was left in an open container for about 15 minutes, the odor was gone. Apparently, the odor was caused by a reaction of the stored urine with the Chemtric urine pretreatment solution; the same odor occurred when this solution was mixed with deionized water and then heated. The specified dose of the additive, 1.3 percent by weight of urine, was used initially and then reduced to 0.78 percent on the fourth day of testing. On the fifth day, the product water had a slightly milder odor. The percent of additive was reduced to 0.65 percent and then further reduced until none was added.

On 2 November 1972, after brine loop ΔT (T2-T1) dropped to 2^{0}F, the flash valve was opened to allow a higher brine flowrate. It was also noted that the separator speed had decreased to 960 rpm. The motor control was adjusted to 1125 rpm, after which the brine in the loop was dumped manually to abort the cycle.

On 3 November 1972, after the system had operated for 317 hours, compressor speed dropped suddenly and became unstable. Power required to run the compressor increased markedly. The laboratory motor used to drive the compressor was shut off after becoming noisy. The motor was repaired by replacing the bearing (magnetic end). Gas cooling for the bearing was also provided. An analysis of the bearing removed from the motor is given in Figure 3-34.

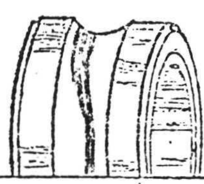
The system was put back in operation after seven hours of compressor down time. After the system operated for five hours, a noticeable increase in brine loop ΔP (P1-P2) occurred. The urine brine was dumped and the loop was flushed with water. The system was back in operation after one hour of down time.

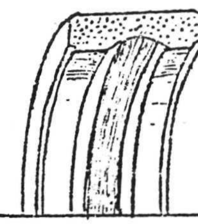
By 0900 hours on 6 November 1972, the system had operated continuously for 387 hours and was producing water at an average rate of 0.58 lb/hr. Meter readings showed that the compressor and separator had been operating for 498 hours and 698 hours, respectively.

OPERATING DATA	BEARING REPORT BR 721211-5-1209
497.1 HOURS .280 GRAM KRYTOX 280 AB GREASE.	UNIT: COMPRESSOR MOTOR P/N: S/N: BEARING: 100 SS 5 BARDEN DIST.: R. JOHNSON R.O.:

NO. I ____________ BEARING

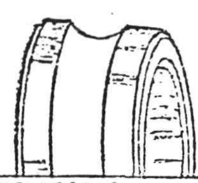
INNER RING	SEPARATOR	OUTER RING
BALL PATH SHOWS HEAVY UNBALANCE AND MISALIGNMENT.	WEAR OF O.D., BORE & POCKET EXTERNAL AND INTERNAL SURFACES.	WIDE TRACK.
	BALLS	
	O.K.	

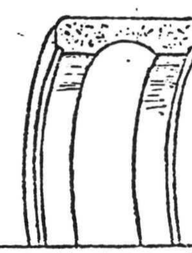




NO. II ____________ BEARING NOT EXAMINED.

INNER RING	SEPARATOR	OUTER RING
	BALLS	





CONCLUSIONS: THE BEARING FELT DRY WHEN ROTATED BEFORE DISASSEMBLY.

CONDITION	I	II
BALANCE		
LOADS		
ALIGNMENT		
LUBRICATION		

WHEN THE BEARING COMPONENTS WERE TAKEN APART, IT BECAME EVIDENT THAT THE INNER RING WAS OPERATING IN A SEVERELY MISALIGNED POSITION, THE PRESENCE OF RADIAL UNBALANCE MADE THE OPERATING CONDITIONS WORSE. THE RESULTING ERRATIC MOTION OF THE SEPARATOR CAUSED WEAR OF ITS SURFACES, WEAR OF SHIELD SURFACES BECAUSE OF RUB AND MIXING OF WEAR PRODUCTS WITH THE GREASE. 100 HOURS OF ADDITIONAL OPERATIONAL CAPABILITY IS UNLIKELY.

12-11-72
DATE

R. BHIKHA
BEARING COORDINATOR

Figure 3-34. Motor Bearing Analysis

The brine loop ΔP again increased noticeably on 8 November 1972. After removing the brine, the loop was flushed with water and nitrogen gas to clean out the solids buildup.

Measurement of brine density on 10 November 1972 showed that the solids concentration at brine dump had reached 61 percent, as compared with the design point of 50 percent. The density sensor calibration was checked and control settings were readjusted in an attempt to establish the desired 50-percent brine dump level. Product water on 11 November 1972 had an ammonia odor.

On 12 November 1972, the pyrolysis reactor heat controller malfunctioned. The heater was shut off and temperature dropped from 850^0 to 400^0F before the control could be reset. Product water odor on that day and the next day was not as strong as that noted on 11 November, but was somewhat stronger than the previous musty odor. By 0900 hours on 13 November 1972, the system had run for 561 hours, with an average water production rate of 0.58 lb/hr.

Product water samples were taken on 23 and 25 October and on 3, 8, 16, and 19 November for NASA chemical analysis. Results of the analyses for these samples and for the separator overboard water sample taken at the end of the 30-day test are shown on Table 3-3. For the first 20 days of test, the ammonia content was within acceptable limits. During the remaining 10 days, the ammonia content was excessive, indicating that the pyrolysis reactor was no longer effective.

On 16 November 1972, urine would not feed into the separator. After removing a small solids deposit from the fitting on the urine feed line at the brine loop, urine feed into the separator was resumed.

The 30-day urine test was completed on 20 November 1972 after the system had been in operation for 720 hours. Compressor and separator system test run times were 727.4 hours and 722 hours, respectively.

Before the test setup was dismantled, trouble shooting was conducted, using a laboratory-type condenser attached to the pyrolysis reactor outlet, to determine the cause of the high ammonia content in the product water. The same amount of ammonia was found in the product water as in the separator overboard water, which did not pass through the pyrolysis reactor. This comparison proved that the high ammonia content in the product water was caused by failure of the pyrolysis reactor.

TABLE 3-3

NASA WATER ANALYSIS DURING 30-DAY TEST

Sample Identification:	Product Water from Urine Water Recovery System							SEPARAT OVERBD WATER SAMPLE
Source: AiResearch	No	1172-1	1172-2	1172-10	1272-3	1272-4	1372-5	
	Date	10-23-72	10-25-72	11-3-72	11-8-72	11-16-72	11-19-72	
	Hours	63	111	327	450	639	711	
ANALYSIS	LIMIT	ANALYSIS RESULTS						
pH	6-8	6.49	6.71	7.13	7.07	9.03	9.17	5.94
Resistivity (Megohm-cm at 25 deg C)	Ref. only	0.02	0.025	0.015	<0.01	<0.01	<0.01	--
Total Solids, ppm	500	94.5	56.5	50.5	74.0	113.7	82.6	--
Organic Carbon, ppm	100	38.0	36.0	42.0	23.0	100	125	500
Inorganic Carbon, ppm	Ref. only	8.5	6.0	16.5	40.0	525	1100	1150
Cadmium as Cd, ppm	0.01	0.03	0.08	≤0.01	≤0.01	≤0.01	≤0.01	--
Chromium as Cr^{+6}, ppm	0.05	<0.005	<0.005	<0.005	--	--	--	--
Copper as Cu, ppm	1.00	<0.05	<0.05	<0.05	<0.5	0.08	0.08	--
Iron as Fe, ppm	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	--
Lead as Pb, ppm	0.05	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	--
Magnesium as Mg, ppm	Ref. only	1.1	0.075	<0.01	<0.01	<0.01	<0.01	--
Manganese as Mn, ppm	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
Mercury as Hg, ppm	1.005	--	--	--	--	--	--	--
Nickel as Ni, ppm	0.05	<0.5	<0.5	<0.5	<0.5	<0.5	<0.05	--
Potassium as K, ppm	Ref. only	0.35	0.40	0.40	0.40	0.50	0.75	--
Silver as Ag, ppm	0.05	<0.05	<0.05	<0.05	<0.05	0.20	0.10	--
Sodium as Na, ppm	Ref. only	7.6	3.3	2.2	2.6	5.9	2.6	--
Zinc as Zn, ppm	5.0	<0.01	<0.01	<0.01	0.03	0.03	0.08	--
Ammonia as N, ppm	3.0	3.0	3.0	2.5	3.0	480	1325	650
Flouride as F^-, ppm	2.0	0.14	0.18	<0.05	0.30	0.15	0.35	--
Nitrate as NO_3^-, ppm	TBD	<0.05	<0.05	--	--	--	--	--
Sulfate as SO_4^{-2}, ppm	450	7.0	8.4	12	--	--	--	--
Chlorides as Cl^-, ppm	450	--	--	--	--	--	--	1600

Post-Test Examination and Analysis

After the 30-day run was completed, the breadboard system was dismantled for inspection. All major components were disassembled and carefully examined for evidence of damage or deterioration such as corrosion and wear and for the presence of solids deposits or entrapped brine. Observations made during this post-test examination are discussed below.

1. Phase Separator

The disassembled phase separator is shown in Figure 3-35. Detail parts are shown in Figures 3-36 through 3-42. Upon disassembly, approximately 10 cc of urine brine was found on the bottom plate of the outer bowl; no brine was found on the outside of the inner bowl. The magnetic coupling cover was moist and smelled of urine.

The presence of urine on the bottom plate of the outer bowl appeared to be an indication that misting or foaming (or both) occurring in the inner bowl during the test. In all probability, the antifoam used in the urine pretreatment solution was not transported to the brine loop in sufficient quantities to reduce foaming. Tests have indicated that this antifoam does not remain in solution at room temperature. Other antifoams are available that will remain in solution and, therefore, will be more effective as a foam inhibitor in the separator than the antifoam used during the test.

A buildup of salt deposits was observed on all internal parts of the unit. The largest buildup was found on the inner periphery of the rotating bowl, above the pitot brine pickup point (see Figure 3-36). The inside of the pitot tube outlet, shown in Figure 3-37, also had a buildup; however, no salt deposit was found in the pitot brine pickup (see Figure 3-38). The upper part of the rotating bowl had salt deposits caked on the outside of the spool (see Figure 3-39). No evidence of salt was found inside the spool.

Examination of the two separator bearings after 868.5 hours of operation showed that the top bearing was in excellent condition and the bottom bearing had some superficial corrosion pitting, both externally and internally. Further details are described in the bearing analysis, Figure 3-43.

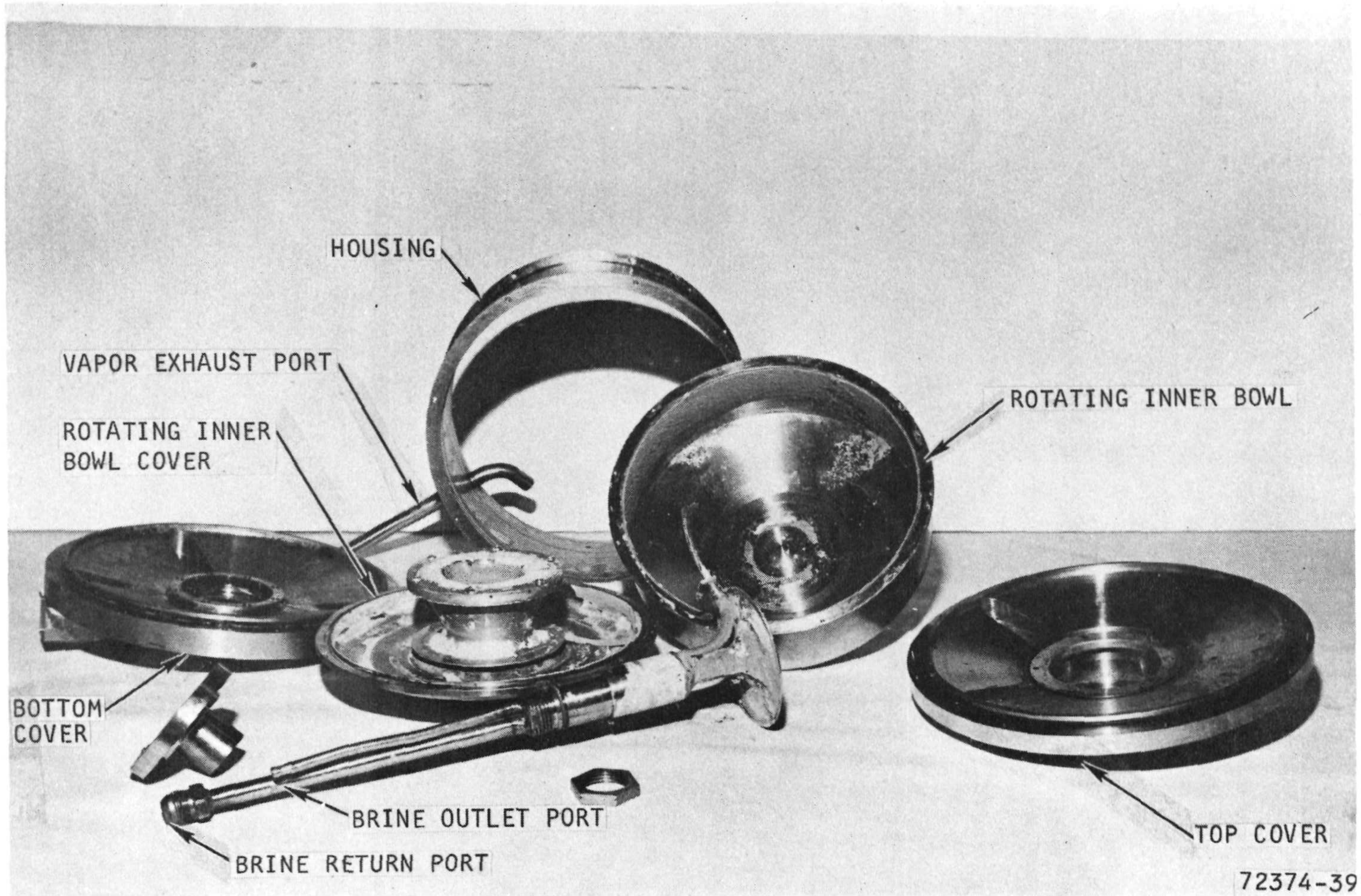


Figure 3-35. Phase Separator--Disassembled

Figure 3-36. Lower Half of Bowl--Phase Separator

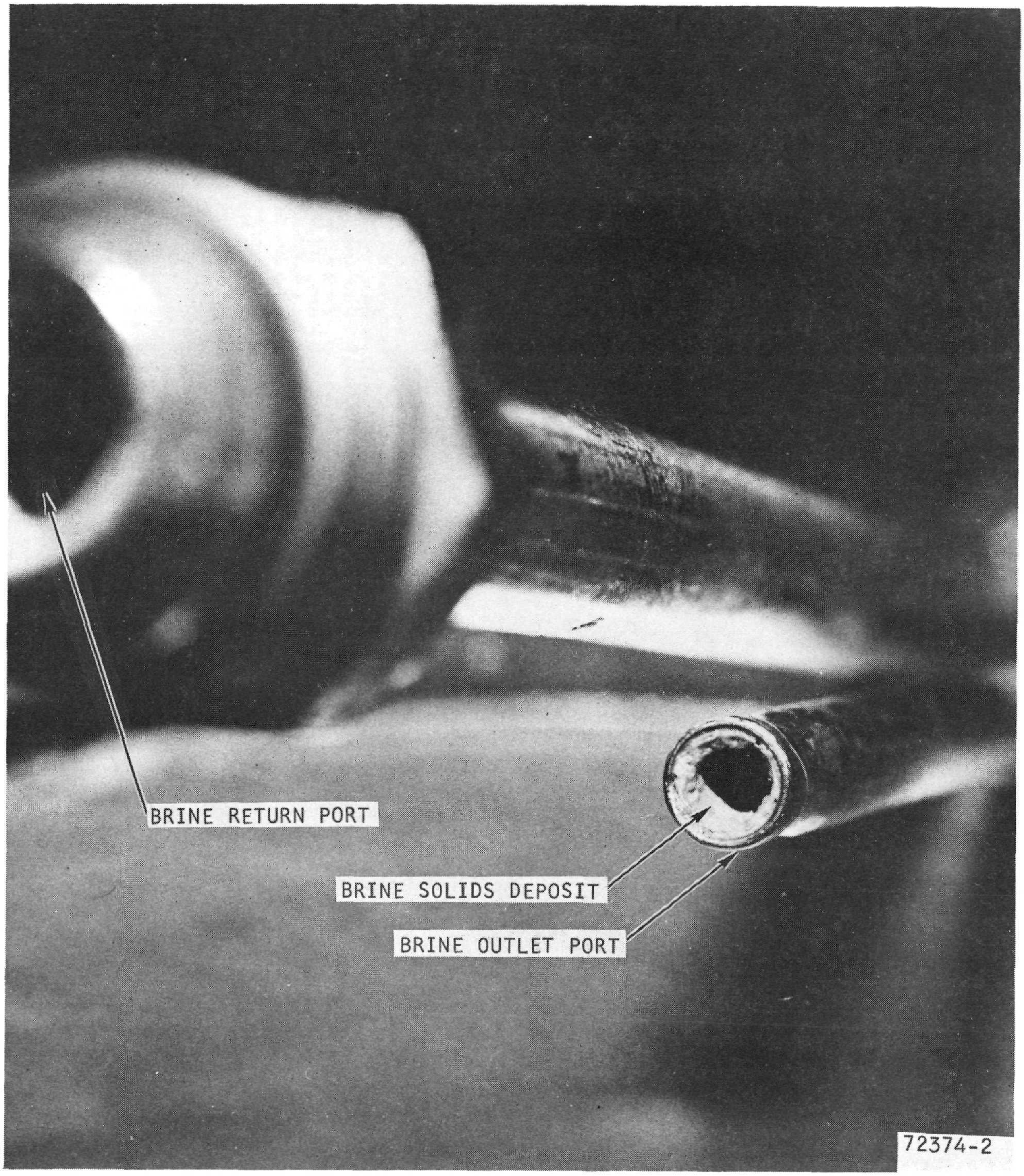


Figure 3-37. Separator Brine Outlet Tube

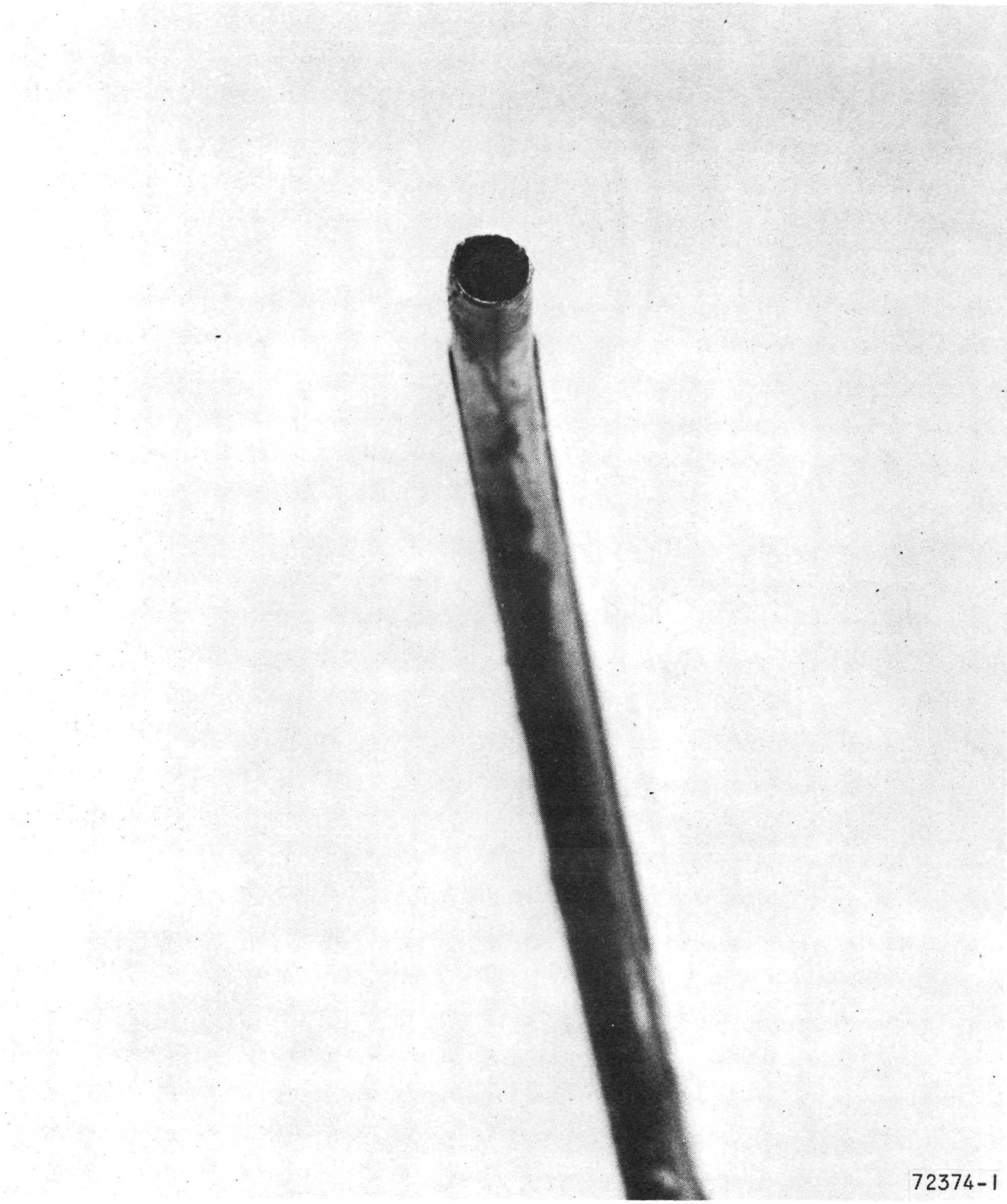


Figure 3-38. Separator Brine Pitot Tube

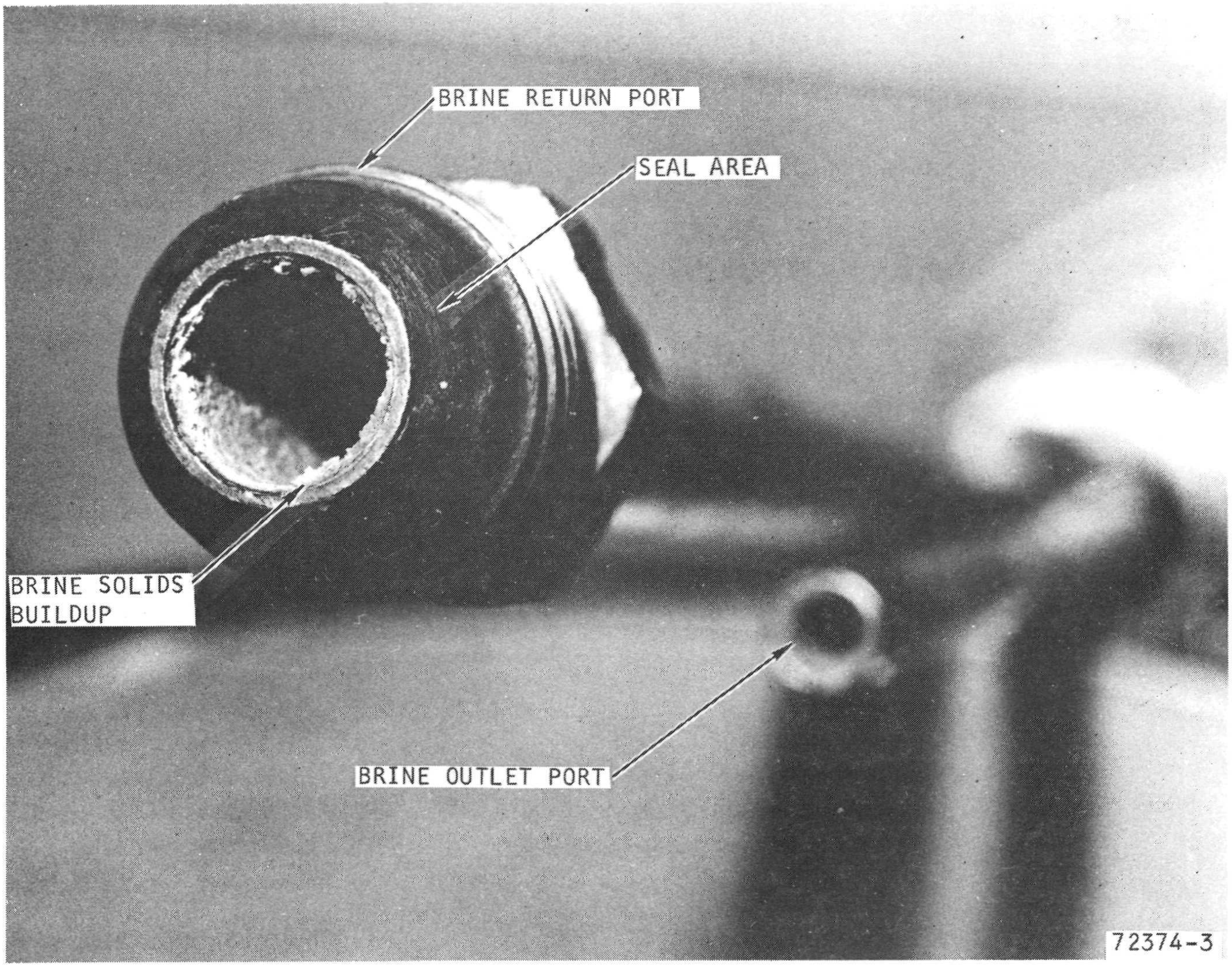
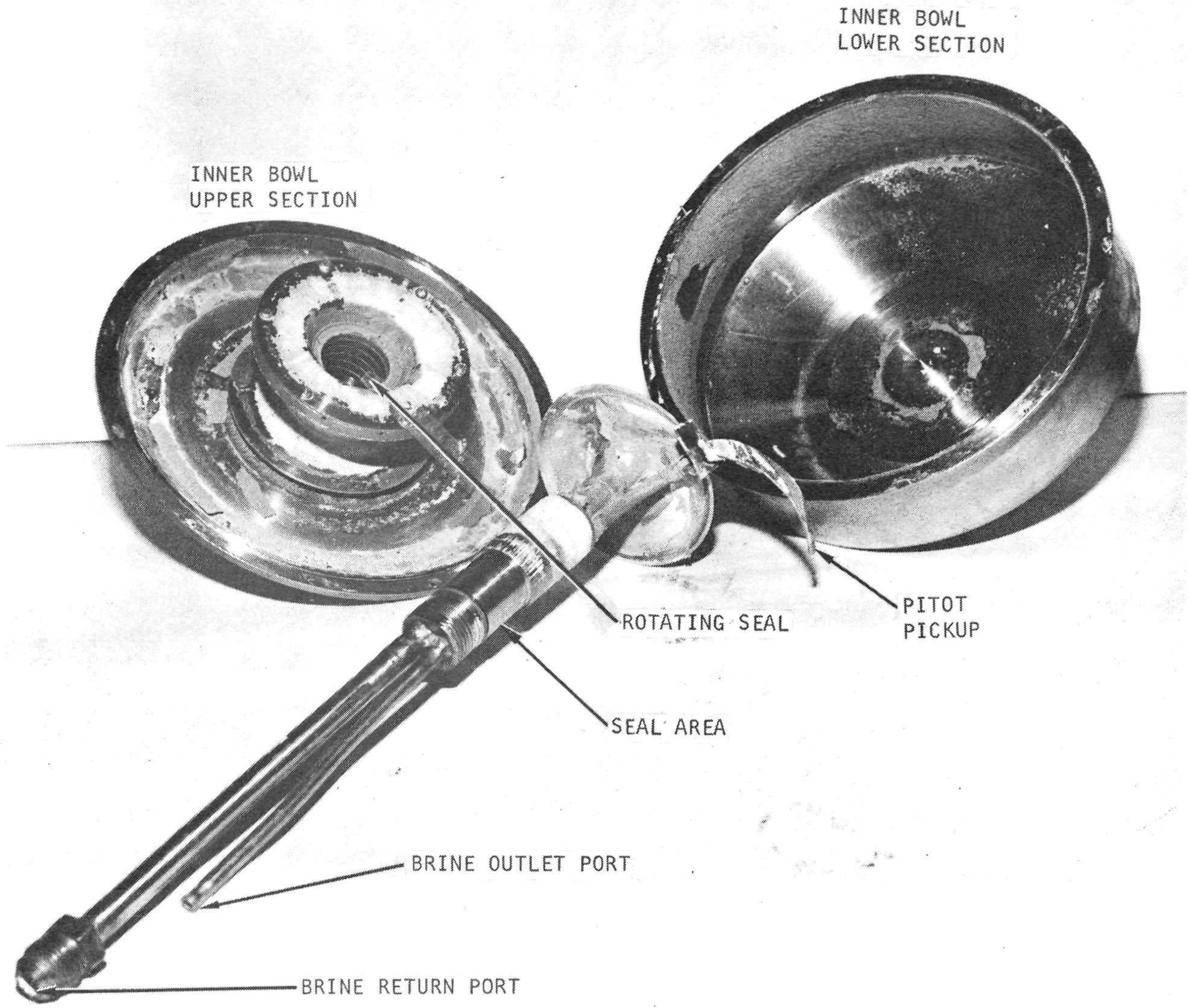


Figure 3-39. Phase Separator Brine Inlet Tube



72374-19

Figure 3-40. Phase Separator Inner Bowl--Disassembled

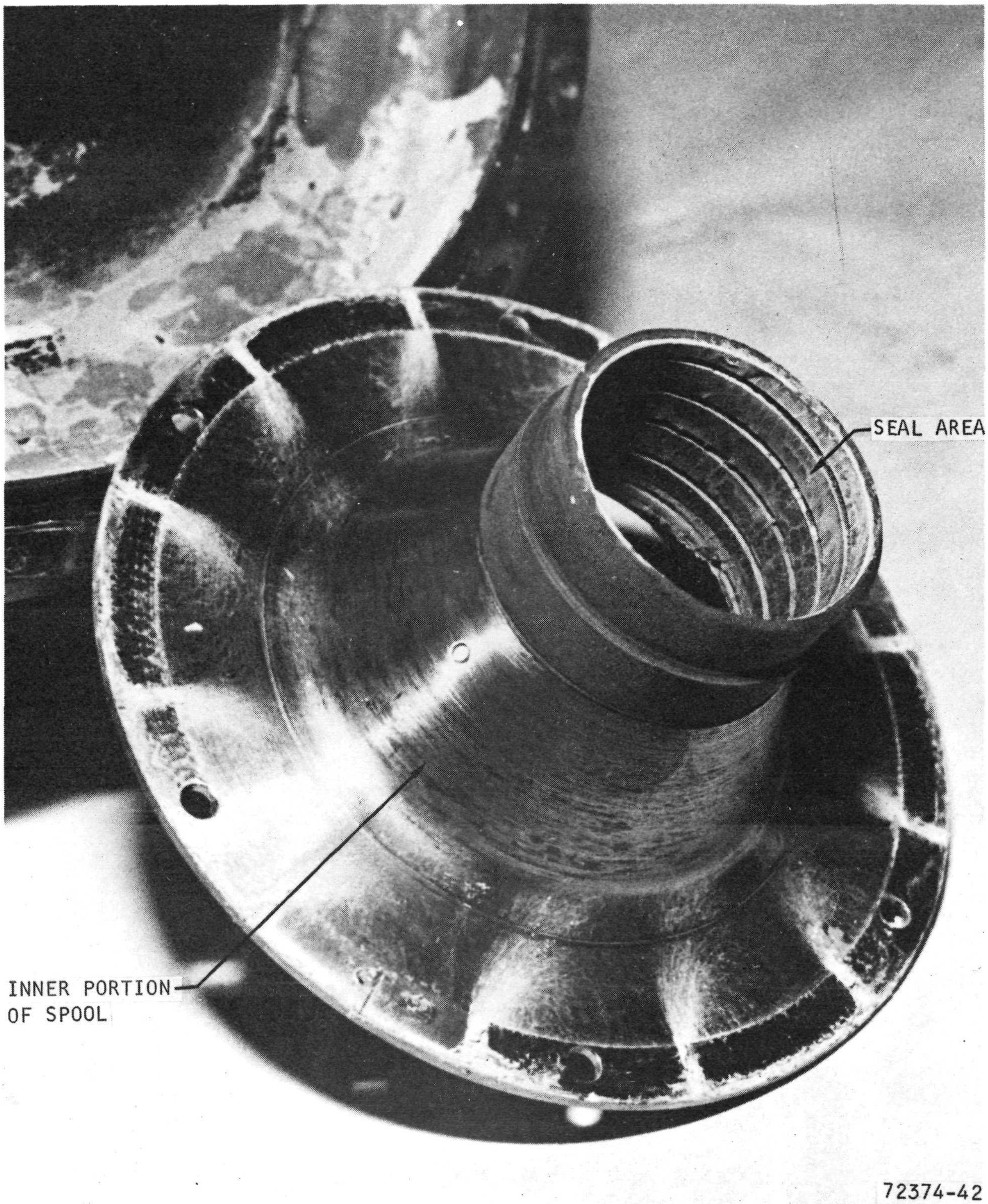


Figure 3-41. Phase Separator Inner Bowl Spool

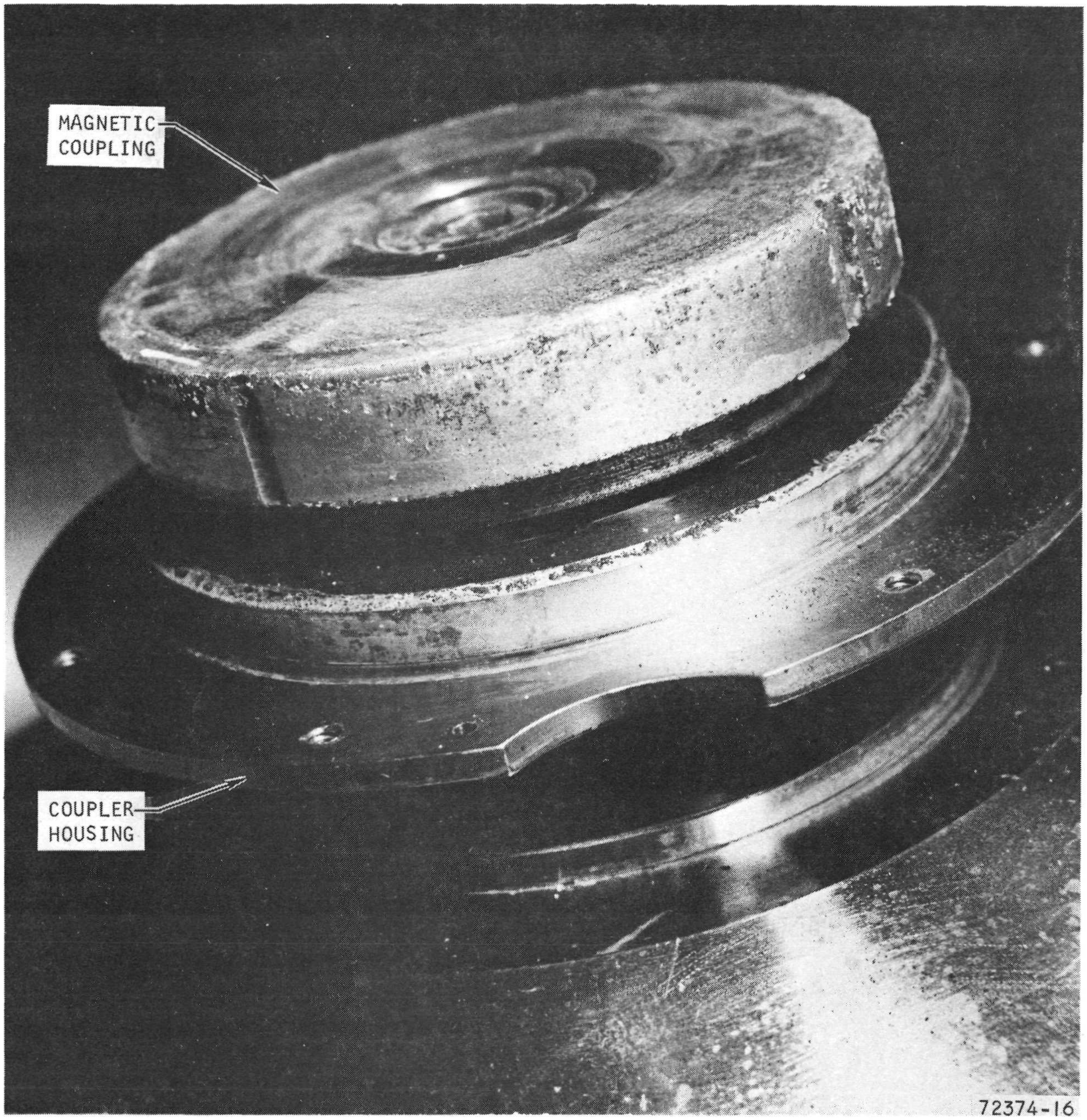
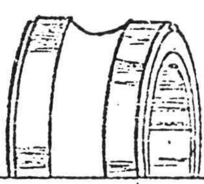


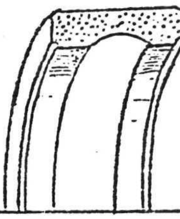
Figure 3-42. Separator Driven (Inner) Magnet

OPERATING DATA	BEARING REPORT BR 721208-5-1208
868.5 HOURS	UNIT: SEPARATOR
NO PRELOAD. VERTICAL LOCATION.	P/N
500 HOURS @ 1000 RPM	S/N
BALANCE @ 15000 RPM	BEARING
KRYTOX GREASE	DIST. R. JOHNSON
	R.O.

NO. I TOP BEARING (9107 PPC FAFNIR) FAINT CORROSION OF I
MEDIUM " " $\overline{\text{O}}$

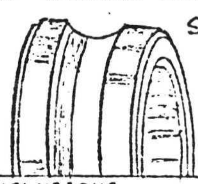
INNER RING	SEPARATOR	OUTER RING
O.K.	O.K.	O.K.
	BALLS O.K.	

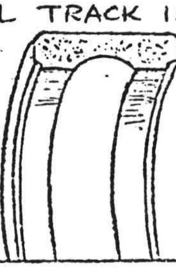




NO. II BOTTOM BEARING (9105 PP FAFNIR) DEEP CORROSION OF ALL EXTERNAL SURFACES.

INNER RING	SEPARATOR	OUTER RING
SUPERFICIAL CORROSION OF INTERNAL SURFACES. BALL TRACK IS BRIGHT WITH MINOR CORROSION SPOTS.	NO WEAR	SUPERFICIAL CORROSION. OF INTERNAL SURFACES. BALL TRACK IS BRIGHT WITH MINOR CORROSION SPOTS.
	BALLS: SUPERFICIAL CORROSION. BRIGHT SURFACES.	





CONCLUSIONS: THE TOP BEARING IS IN EXCELLENT CONDITION. ITS GREASE LOOKS ALMOST LIKE NEW, HAS NO DISCOLORATION AND IS EXPECTED TO LAST OVER 1000 ADDITIONAL HOURS. CORROSION OF INTERNAL SURFACES IS NOT DISCERNIBLE.

THE BOTTOM BEARING IS CORRODED EXTERNALLY AND INTERNALLY. CORROSION PITS ARE SUPERFICIAL. THE GREASE HAS BECOME DISCOLORED AND THICK. THERE IS NO RACEWAY, BALL OR SEPARATOR WEAR. THE GREASE WILL PROBABLY BREAK DOWN AFTER 200-300 HOURS FURTHER OPERATION AND TOTAL BEARING FAILURE WOULD RESULT AT THAT TIME.

CONDITION	I	II
BALANCE		
LOADS		
ALIGNMENT		
LUBRICATION		

12-11-72
DATE

R. Bhikha
, BEARING COORDINATOR

Figure 3-43. Separator Bearing Analysis

2. Vapor Compressor

No evidence of wear or corrosion was found on any of the compressor components. Some urine brine deposits were observed on the first stage housing channel, as shown in Figure 3-44, indicating that some urine was present in the vapor loop. Other parts of the compressor were in excellent condition (see Figure 3-45).

Examination of the two compressor bearings after 909.5 hours of operation showed that both bearings were in good condition, but that the lubricant had deteriorated somewhat. Further details are described in the bearing analysis, Figure 3-46.

3. Pyrolysis Reactor

The pyrolysis reactor was disassembled for inspection by cutting off both ends of the welded case. The disassembled reactor is shown on Figure 3-47. Photographs of the catalyst bed and screens are shown on Figures 3-48 through 3-50.

Visual examination of the catalyst bed showed that all plating was gone from the screen discs at the vapor inlet (hot) side. Surfaces of the exposed stainless wire appeared to have undergone high temperature oxidation. The rhodium plating on the screen discs at the vapor exhaust (cold) side was intact.

Spectographic analysis of the inlet screen discs showed them to be covered with a black deposit, which was largely copper and rhodium. Some nickel also was present.

Microscopic examination of the discs at various locations in the stack showed severe oxidation on the vapor inlet side, and progressively less oxidation toward the exhaust side. The last disc in the stack appeared to be in good condition, but was coated with an organic residue that analysis showed to be oxides of rhodium and copper from the inlet side discs.

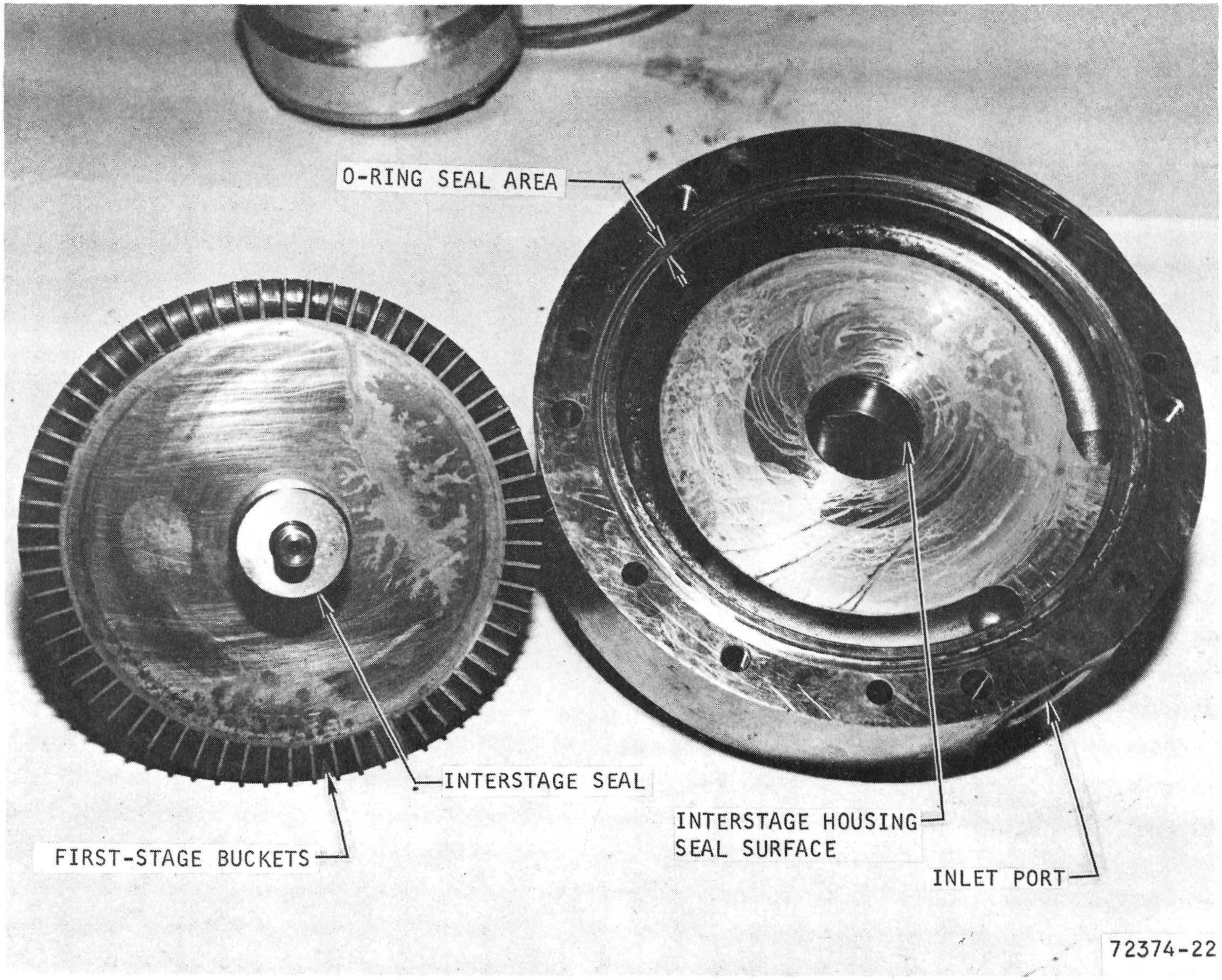


Figure 3-44. Vortex Compressor

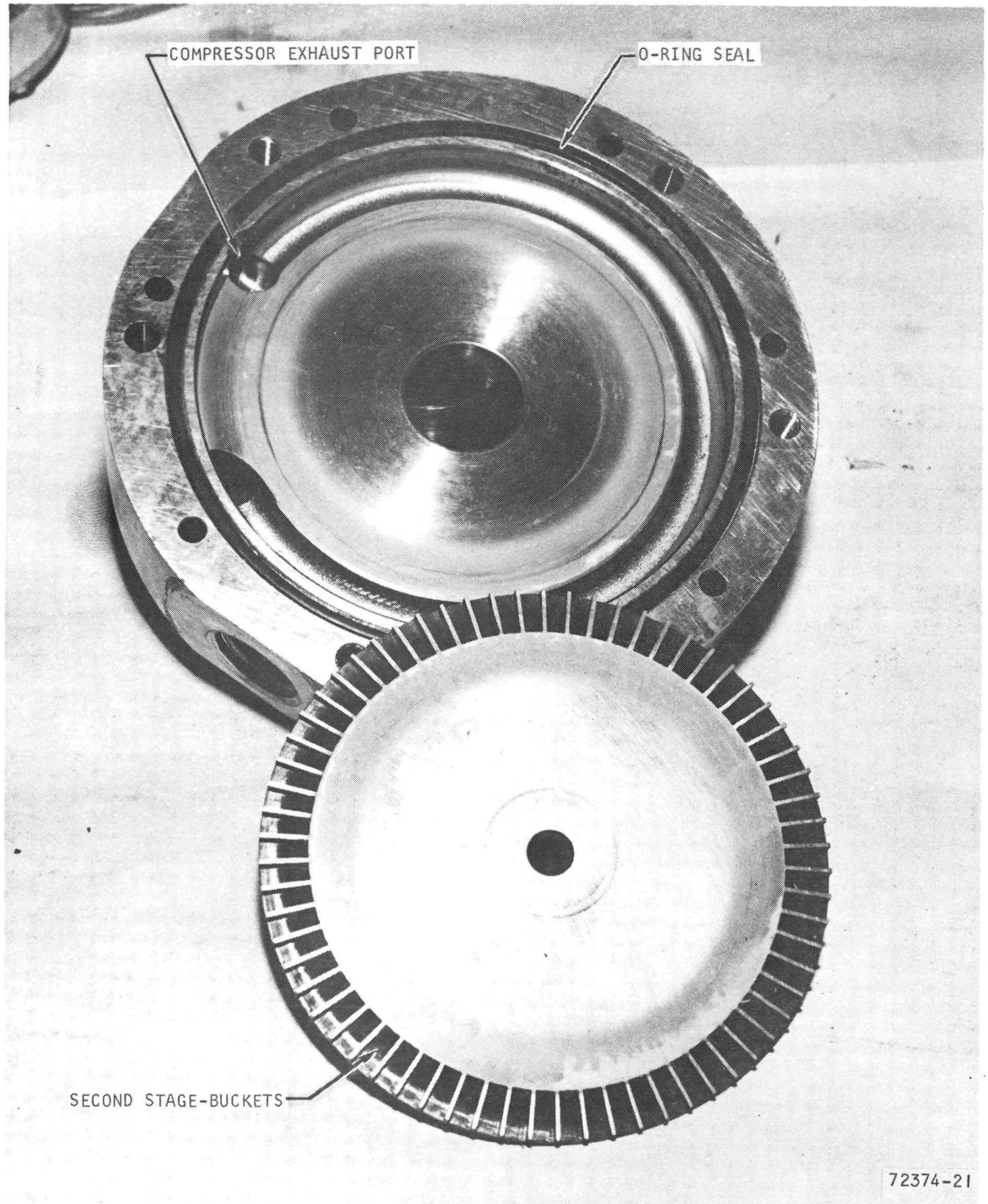
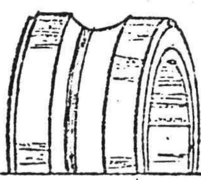


Figure 3-45. Vortex Compressor

OPERATING DATA	BEARING REPORT BR 721208-5-1207
909.5 HOURS 22000 RPM KRYTOX GREASE	UNIT: COMPRESSOR P/N: S/N: BEARING: S38SSTX2 BARDEN DIST.: R. JOHNSON R.O.: 3400-250182-20-0300

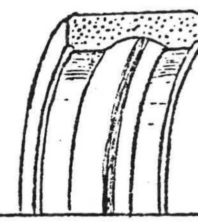
NO. I MAGNET BEARING

INNER RING	SEPARATOR	OUTER RING
LIGHT LOAD TRACK. SMALL DENTS ON TRACK.	FAINT O.D & POCKET RUB SPOTS.	LIGHT LOAD TRACK.



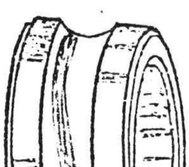
BALLS

O.K.



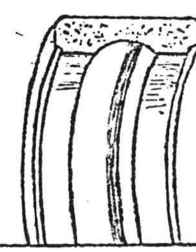
NO. II OUTER BEARING

INNER RING	SEPARATOR	OUTER RING
MISALIGNED LIGHT LOAD TRACK.	FAINT OD AND POCKET RUB SPOTS.	LIGHT LOAD TRACK.



BALLS

O.K.



CONCLUSIONS: THE MAGNET BEARING HAD NO SIGNIFICANT MIS-ALIGNMENT. THE OUTER END BEARING WAS MIS-ALIGNED ON THE SHAFT.

THE BEARING RING, BALL AND SEPARATOR SURFACES ARE IN GOOD CONDITION. THERE IS NO NOTICEABLE WEAR OR DISCOLORATION.

OVER HALF THE GREASE IN EACH BEARING HAS TURNED BROWN AND ITS CONSISTENCY IS THICKER THAN THAT OF NEW GREASE. IT IS FELT THAT THE HALF LIFE OF GREASE HAS BEEN REACHED AND THE BEARINGS ARE GOOD FOR APPROX. 1000 HOURS MORE LIFE.

CONDITION	I	II
BALANCE		
LOADS		
ALIGNMENT		
LUBRICATION		

12-8-72
DATE

R. Bhukla
BEARING COORDINATOR

Figure 3-46. Compressor Bearing Analysis

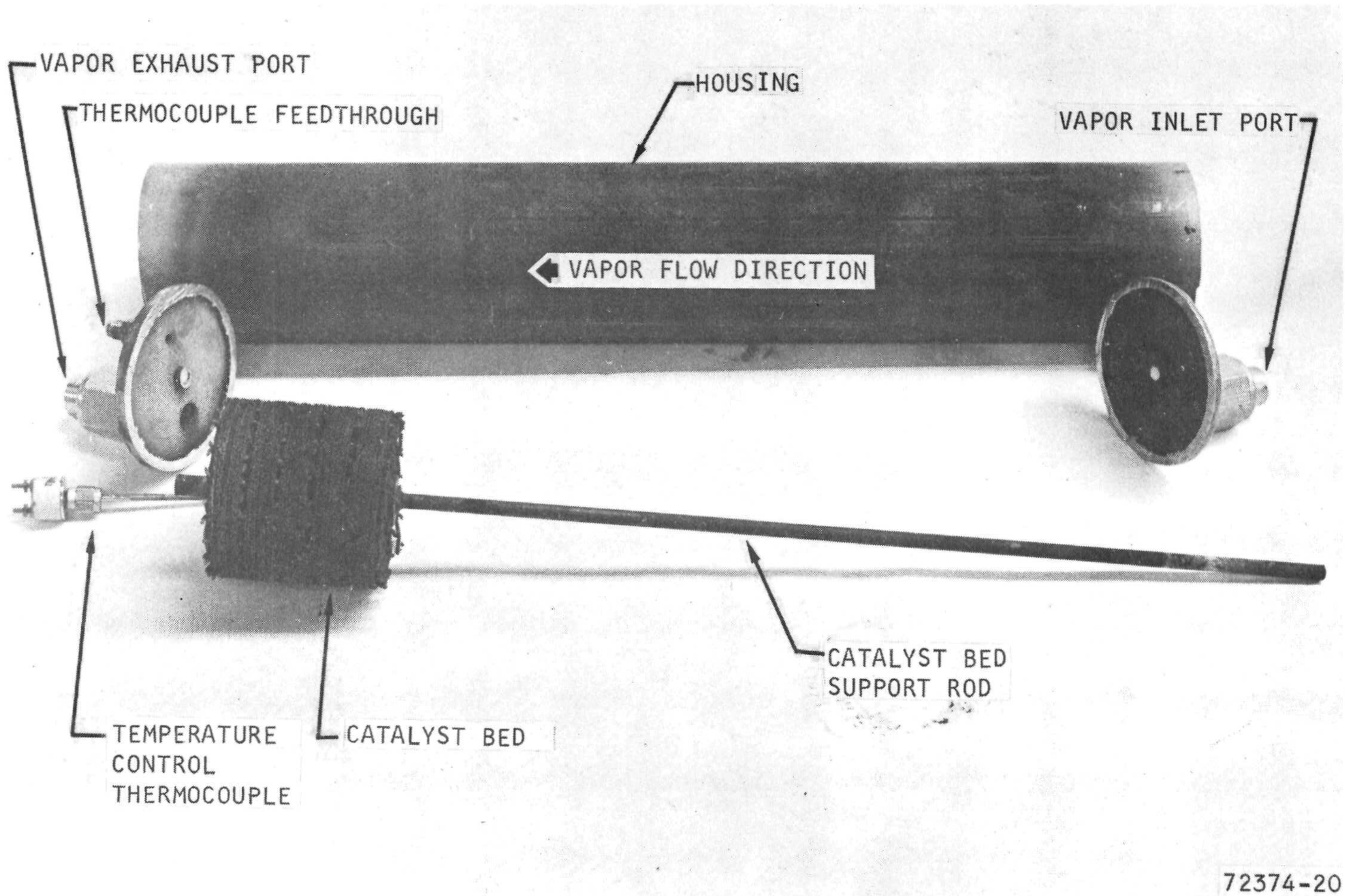


Figure 3-47. Pyrolysis Reactor--Disassembled

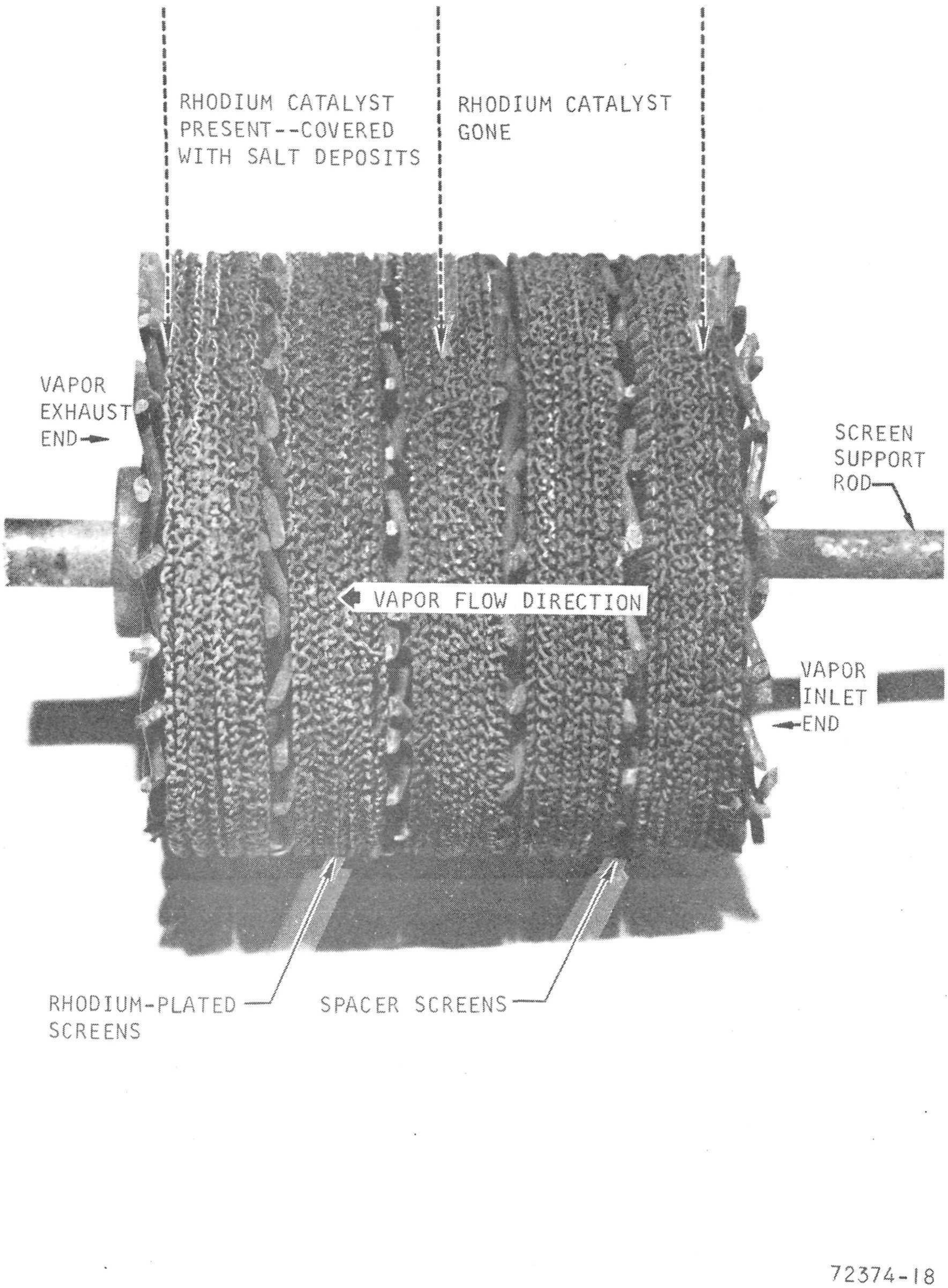


Figure 3-48. Catalyst Bed

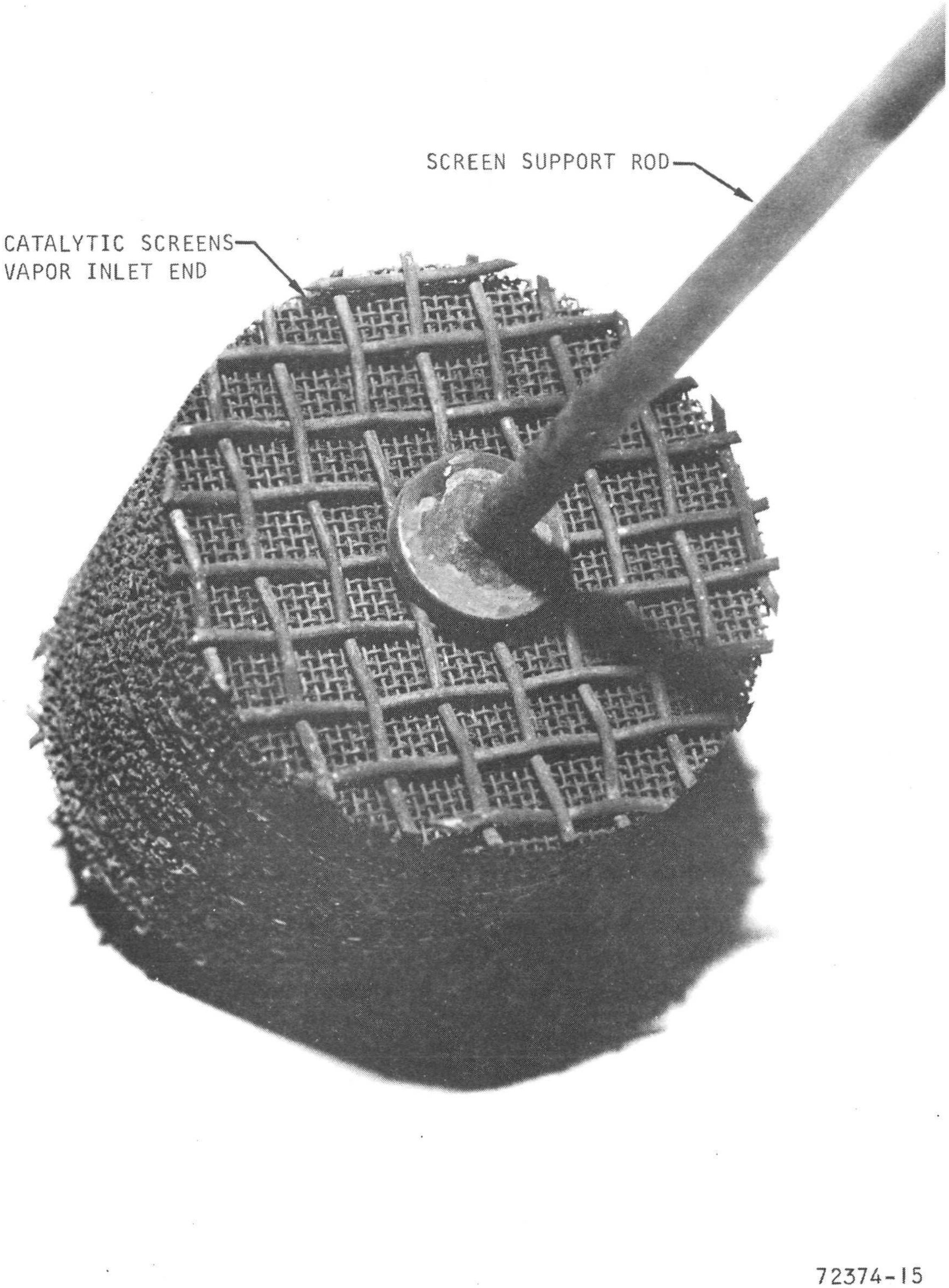


Figure 3-49. Inlet End of Catalyst Bed

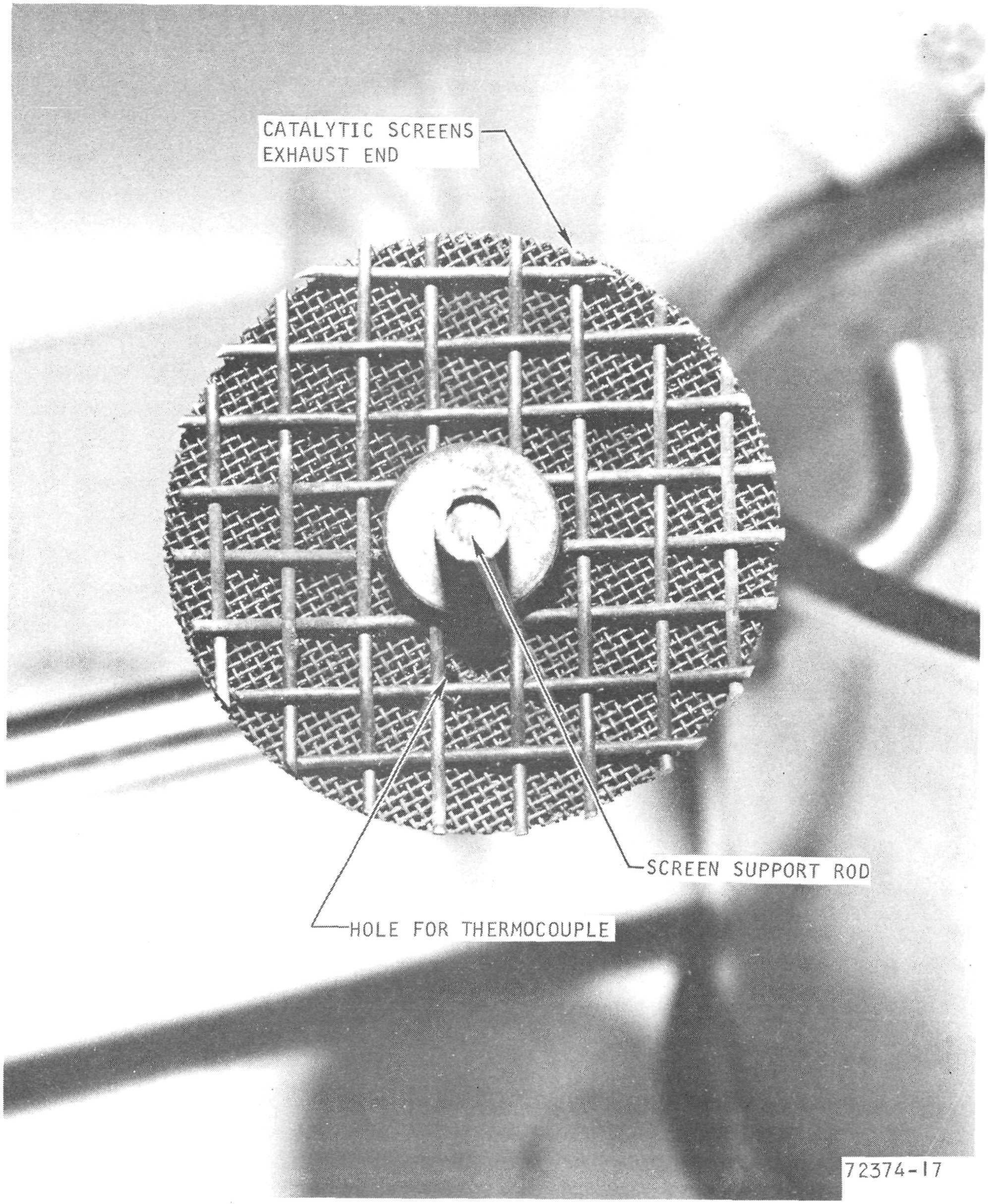


Figure 3-50. Outlet End of Catalyst Bed

The probable cause of the rhodium plating breakdown was the use of stainless steel as a base material. Before plating, the stainless steel base was etched to remove the oxide coating formed by passivation. It then was plated with copper and nickel before the rhodium plating was applied.

In operation, the catalyst bed was exposed to heat, water vapor, and ammonia in an oxygen deficient atmosphere. In the absence of sufficient oxygen to form its own protective coating, the stainless steel wire suffered extensive high-temperature oxidation, which resulted in flaking of the rhodium plating.

New materials being considered for the catalyst bed are discussed later in this report, when recommendations are given for additional areas of investigation based on results of this contractual effort.

4. Heater-Condenser

Examination of heater-condenser parts after disassembly showed that those parts exposed to vapor (see Figure 3-51) were in good condition. No signs of corrosion could be found in the weld areas where the brine and vapor tubes penetrated the housing. As shown on Figures 3-52 through 3-57, salt deposits appeared in all brine loop lines and fittings.

The porous metal "air trap' plates located in the center of the circular plate (see Figure 3-58) appeared to be in good condition. One of the plates was placed in a test fixture and submerged in distilled water. With nitrogen gas at 0.8 psig applied to the inlet side, flow through the plate was 0.636 lb/hr, indicating that performance degradation had occurred. The internal portions of the condenser were swabbed for microbiological analysis, the results of which are presented in an appendix to this report. Rhodium and copper powders from the catalyst bed of the pyrolysis reactor were found on the first glass-fiber pad of the condenser.

5. Cyclic Accumulator

Examination of working parts of the cyclic accumulator after disassembly showed no signs of corrosion or wear. The internal surfaces of the unit after test are shown on Figure 3-59. These surfaces were swabbed for microbiological analysis, the results of which are presented in the appendix to this report.

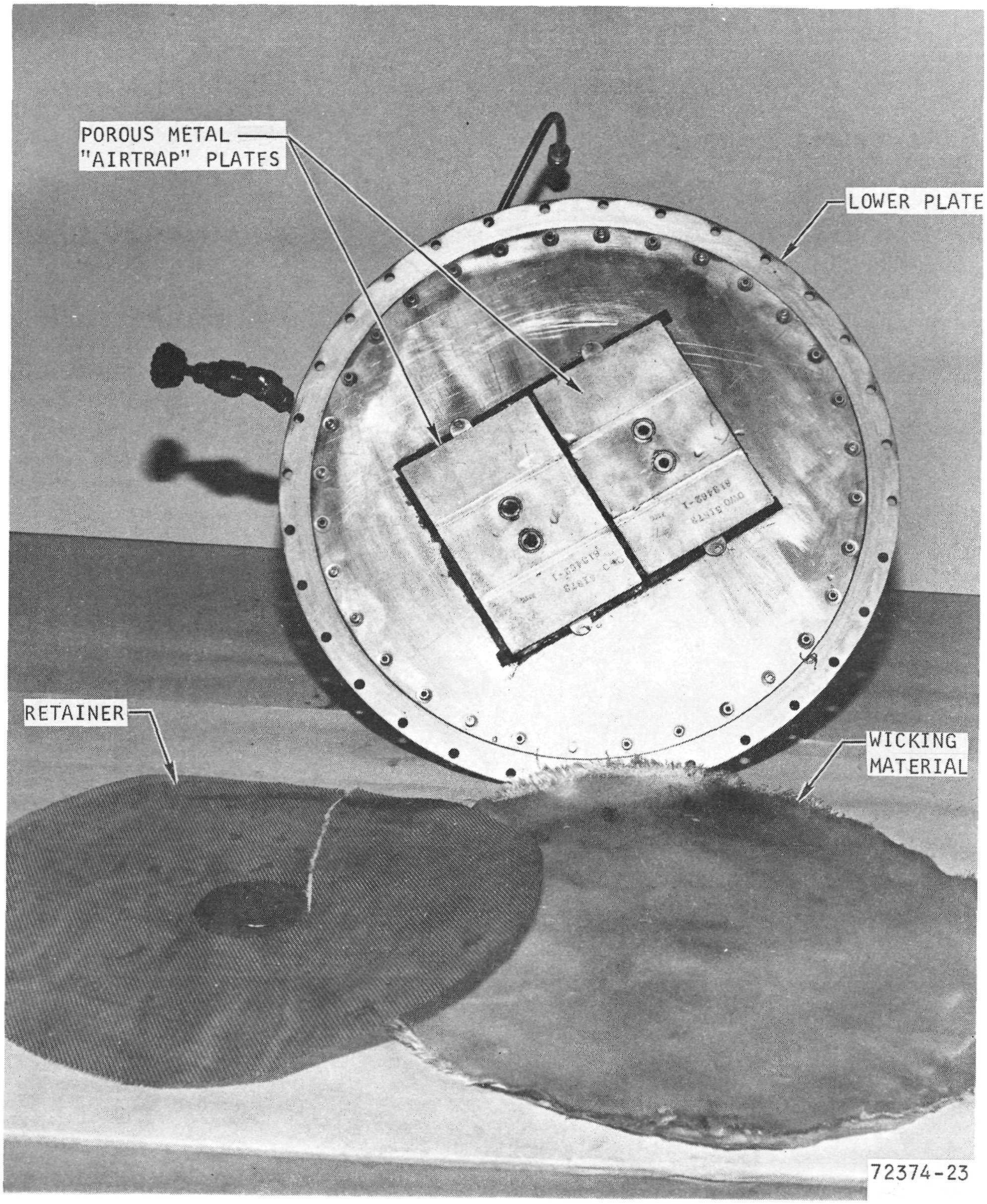


Figure 3-51. Condenser--Disassembled

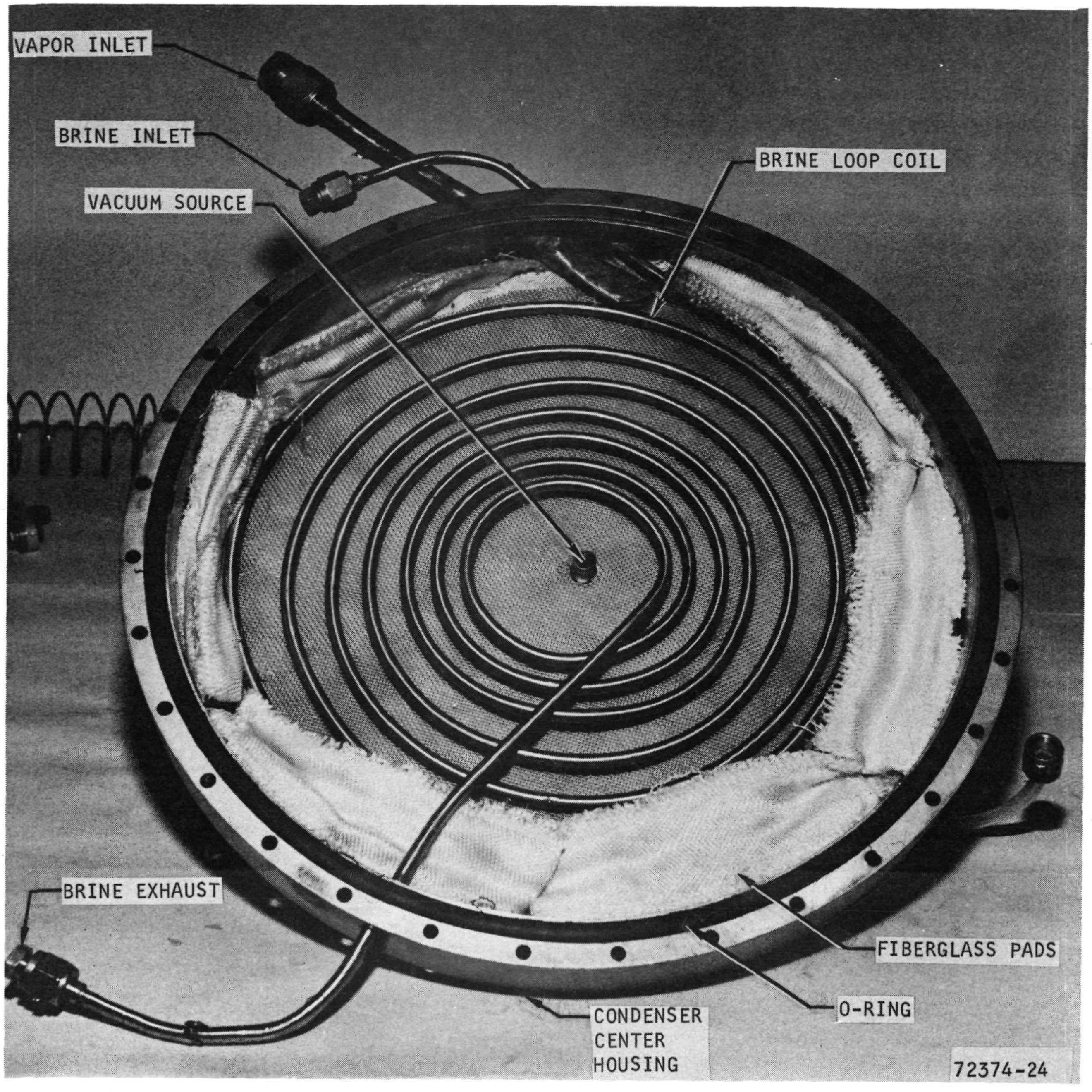


Figure 3-52. Condenser

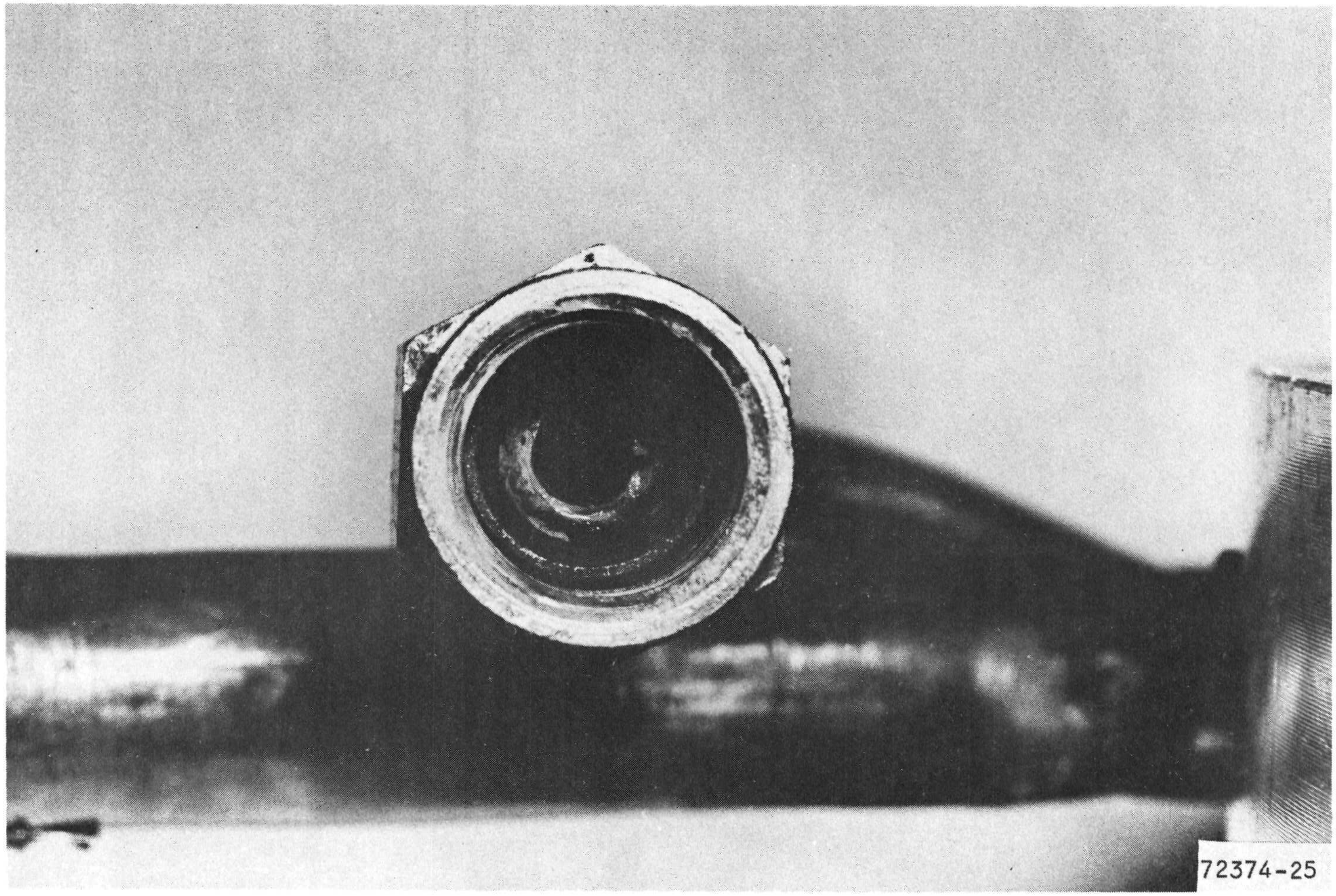


Figure 3-53. Condenser Brine Loop Exhaust Fitting

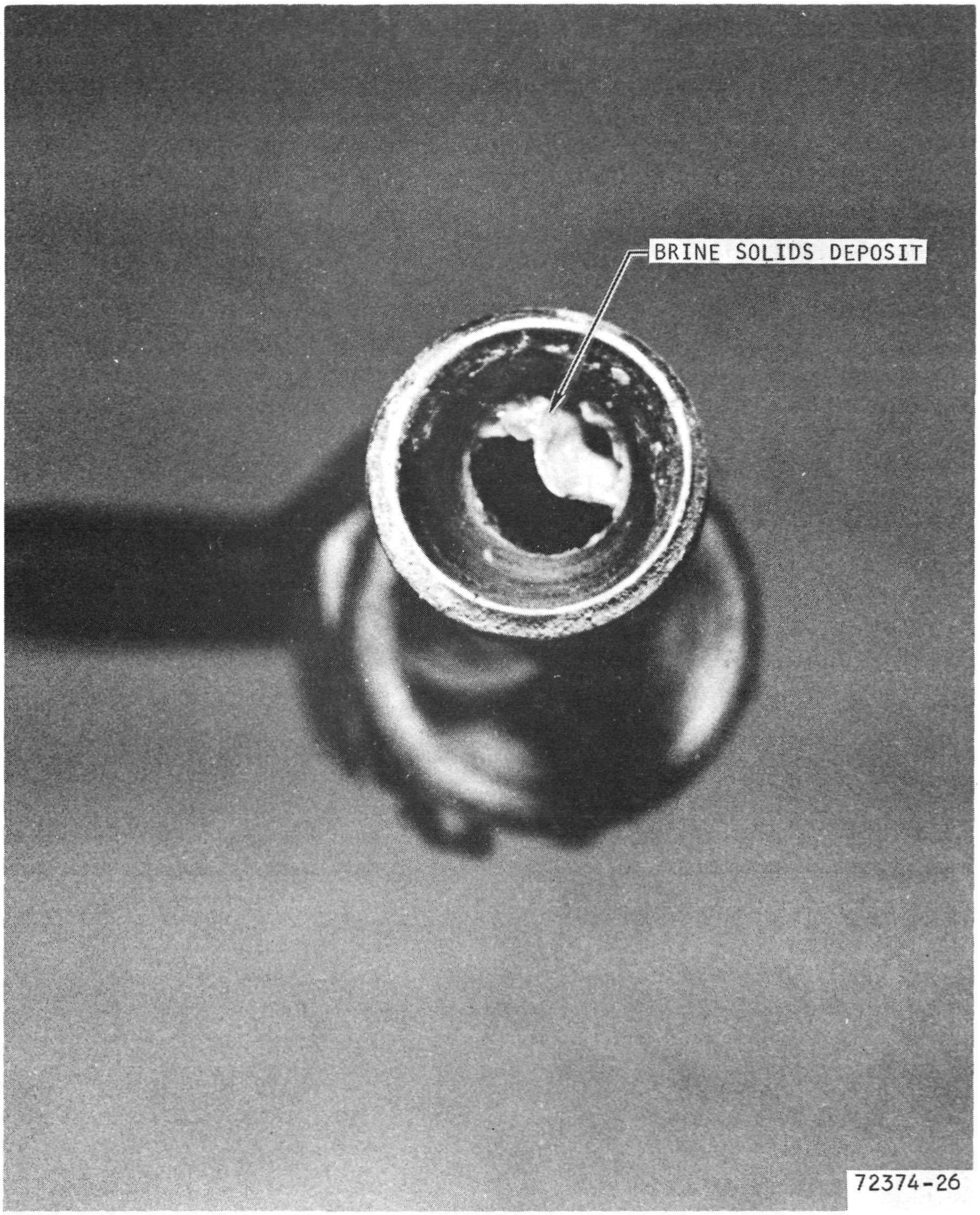


Figure 3-54. Condenser Brine Loop Inlet Fitting

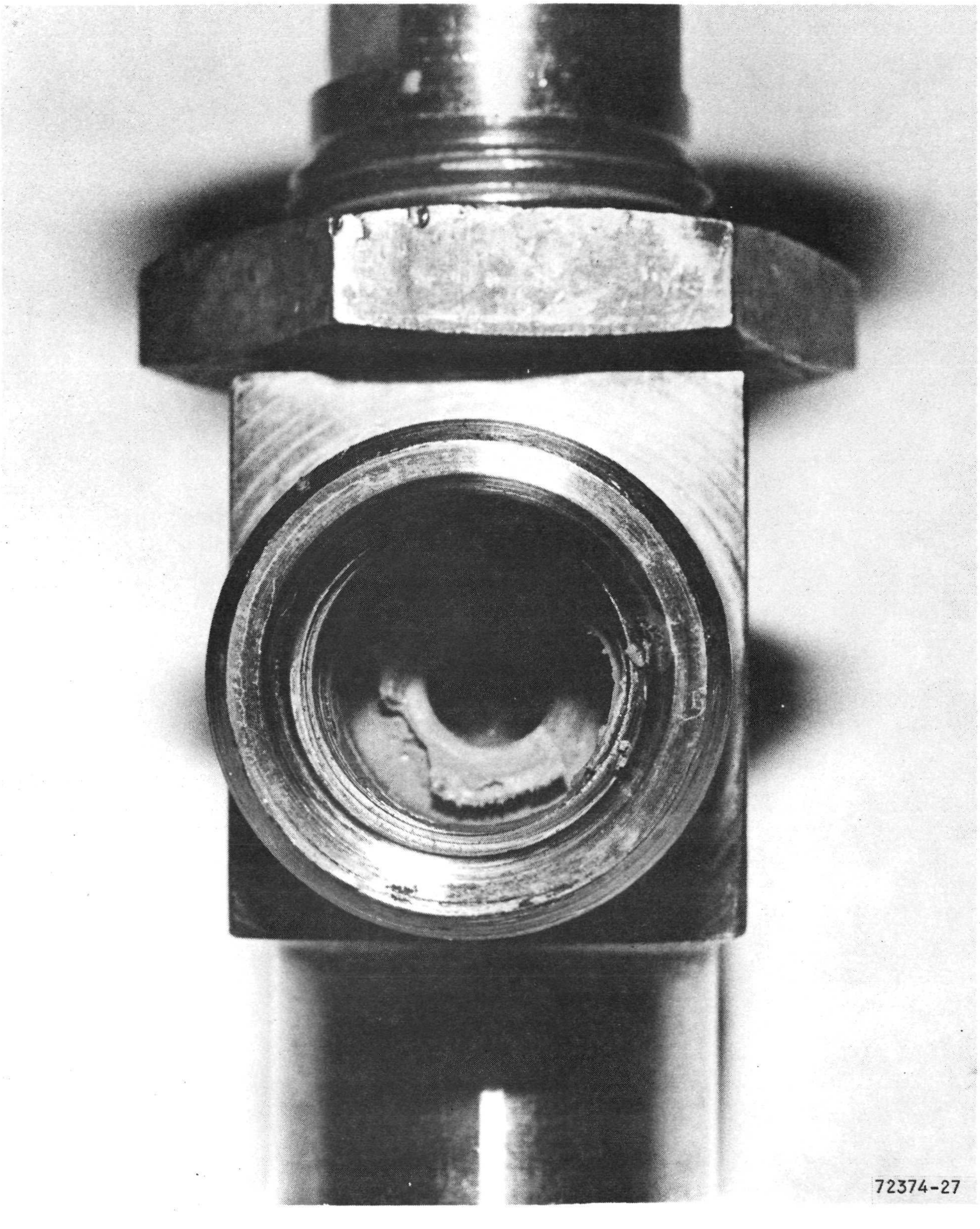


Figure 3-55. Flash Valve Outlet Port

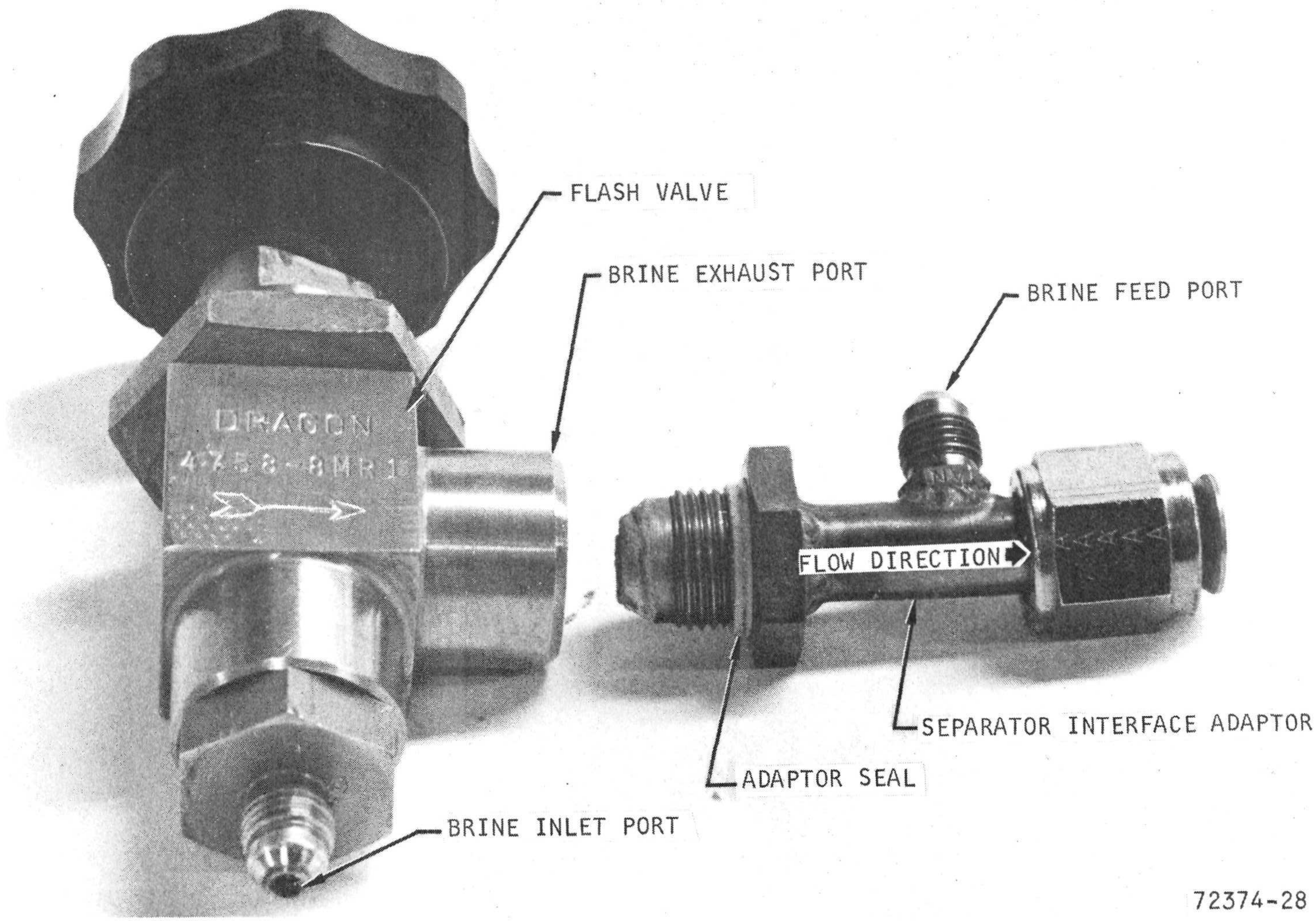


Figure 3-56. Brine Flash Valve and Adjuster

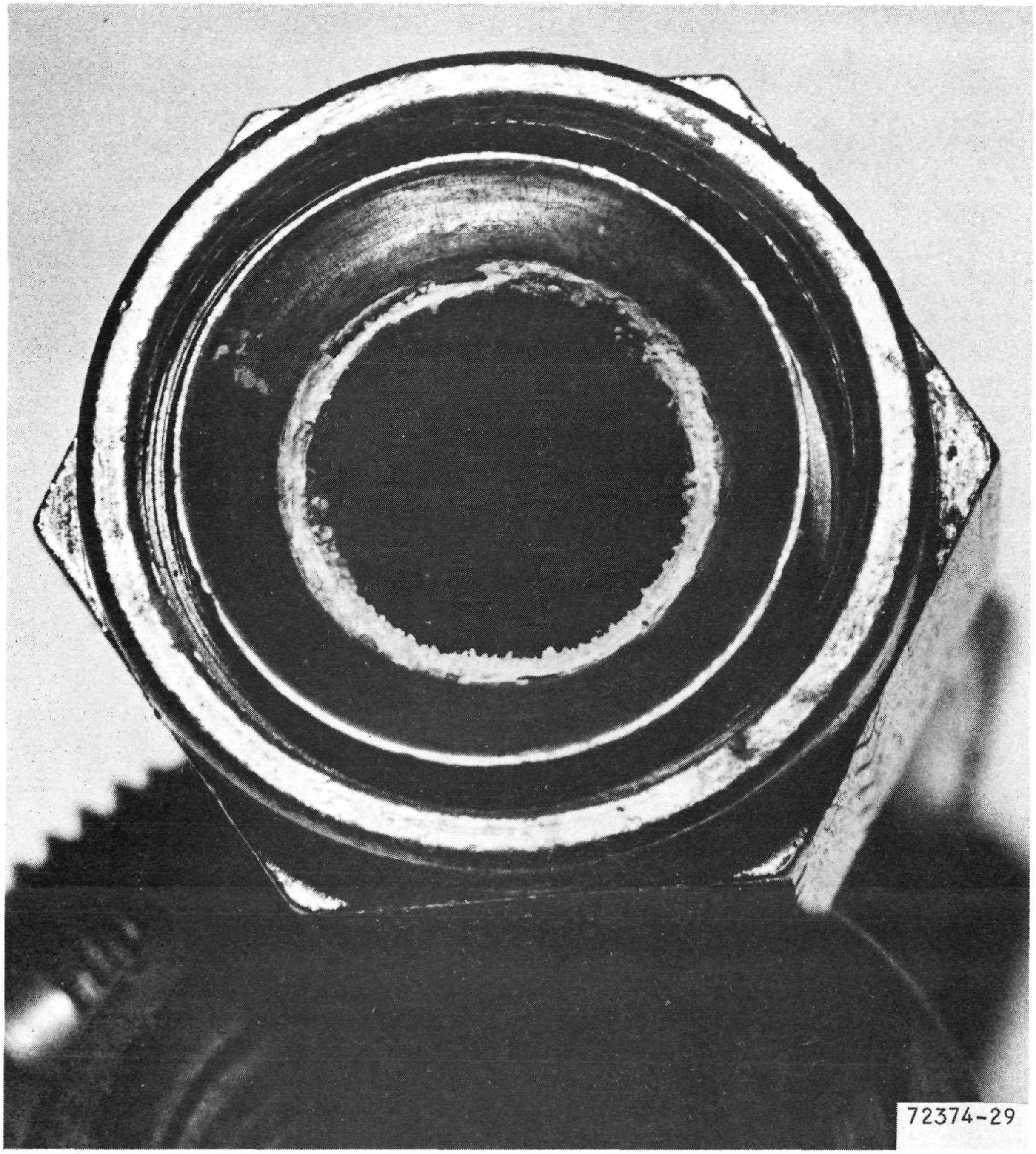


Figure 3-57. Separator Interface Adaptor

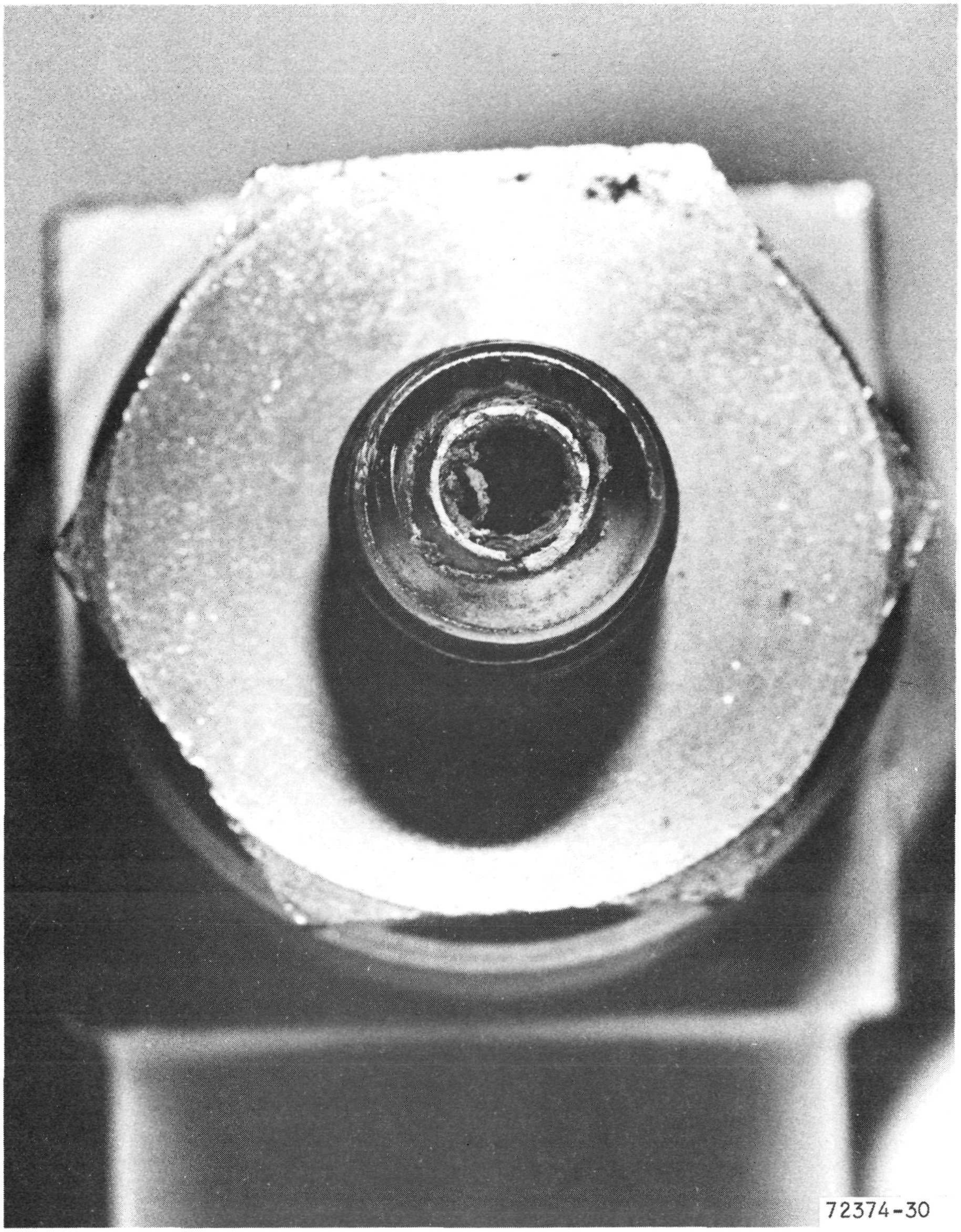


Figure 3-58. Flash Valve Inlet Port

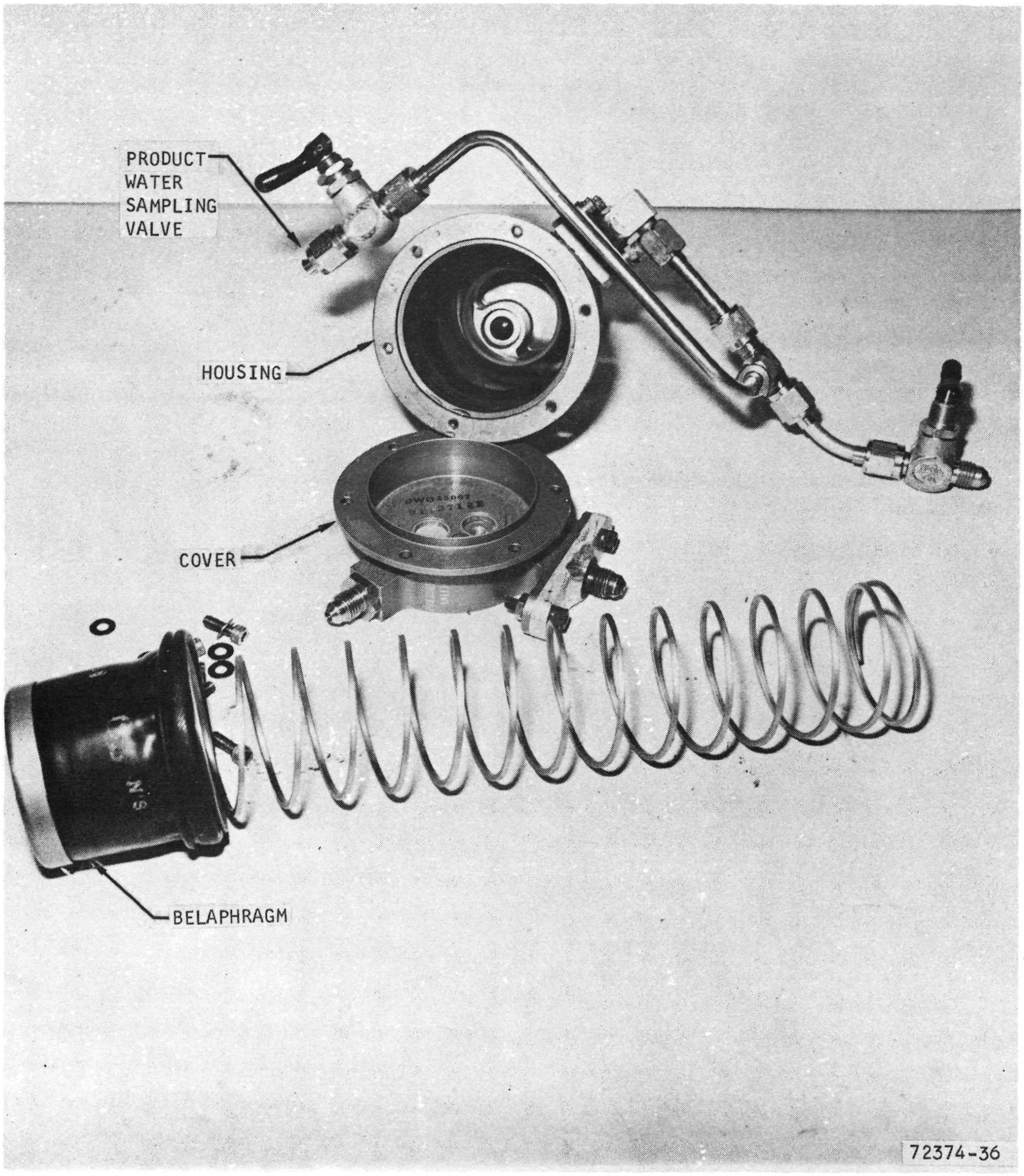


Figure 3-59. Cyclic Accumulator--Disassembled

CONCLUSIONS AND RECOMMENDATIONS

Results of the 30-day IWRS breadboard test demonstrated that 96.4 percent of the water available in the processed urine could be recovered and that clear, sterile water could be produced. Breadboard hardware deficiencies were similar to those encountered when the same components were used during previous system tests.

Brine loop performance was below expectations because of salt buildup inside the heater condenser brine tube. A major improvement in brine loop performance can be made by installing a small liquid pump in the loop to obtain higher brine flow rates and thus reduce salt buildup. Characteristics inherent in the design necessitated operating the phase separator at rotational speeds considerably lower than required to obtain suitable brine loop flow rates. Although phase separation of brine and vapor was more effective than in previous tests, some brine carryover did occur, which could have been caused by misting or foaming (or both) in the separator inner bowl. Investigation has indicated that foaming can be effectively prevented by adding an organo-modified antifoam, such as Union Carbide L-7001, to the urine feed tank. At temperatures below 31.5C (88.7°F), this antifoam will stay in solution with the urine and, therefore, can be transported from the feed tank to the separator bowl. In contrast, most of the antifoam used in the pretreatment solution for the current series of tests probably remained on the surface of the urine in the feed tank.

The corrosion problem with the lower bearing of the separator can be eliminated by using a preloaded, 440-C precision bearing. The same corrosion-resistant steel was used for the vapor compressor bearings, which were found to be in good condition after 1000 hr of operation and were capable of 1000 hr more life. Such bearings are long-lead time items, obtained on special order, and, as such, were not available for use in time for the 30-day test.

Vapor loop performance was below expected goals. New porous plate air trap assemblies are needed in the heater-condenser to obtain higher water production rates. Degradation of the pyrolysis reactor was noted as the test progressed, as evidenced by the excessive ammonia content found in the product water during the last 10 days of test.

An extensive study program is needed to optimize the design of the pyrolysis reactor. In view of the breakdown of the stainless steel substrate in the present design, testing of new catalyst substrates, such as platinum-rhodium and gold, should be performed. Platinum-rhodium wire with 13 percent rhodium is commercially available as a thermocouple wire.

The vapor compressor operated satisfactorily during the test. Examination of the bearings after test indicated that the compressor was capable of operating an additional 1000 hours. Some bearing problems were encountered with the laboratory motor used to drive the compressor. These problems can be resolved by adequately cooling the magnetic-end bearing.

The fluid inventory control system functioned normally throughout the test, but required periodic calibration of the brine level and density settings to optimize IWRS performance. For more efficient operation during long-term testing, it is recommended that adjustable temperature controllers be added to the control system, as required to maintain an optimum thermal balance.

APPENDIX

INTERMEDIATE WATER RECOVERY SYSTEM
MICROBIOLOGICAL ANALYSIS

Prepared by

RONALD NACHUM, PhD.

INTERMEDIATE WATER RECOVERY SYSTEM
MICROBIOLOGICAL ANALYSIS

INTRODUCTION

The production of organoleptically acceptable water supplies from urine aboard spacecraft requires a system designed to provide a microbiologically free potable water supply. The purpose of this part of the test program was to analyze the product water produced in the Intermediate Water Recovery System for the presence of any contaminating microorganisms.

The following sections will present the methodologies used to sample the product water, urine feed, and brine; the results of the studies performed; and the conclusions reached as to the current efficiency of the IWRS for producing a potable sterile water supply.

METHODS

Collection of Urine

Urine was obtained from among employees of AiResearch Manufacturing Company. Urine was collected in five gallon polyethylene or polypropylene containers and refrigerated until used. Individuals donating urine were screened only on the bases of current urinary tract problems (infection) and whether currently under antibiotic therapy. Donors answering in the affirmative to either of these two questions were disqualified.

Since it was felt desirable to keep the growth of the microorganisms to a minimum in the urine feed, treatment of the urine prior to use in the water recovery system was carried out. The urine was treated with 1.3-percent-by-weight of a mixture of water (20 percent), Biopal (67 percent), antifoam (3.62 percent), and sulfuric acid (9.38 percent).

Sterilization of the Water Recovery System

Only the water recovery side of the system was sterilized; i.e., from the pyrolytic reactor to the product water collection tank. Prior to the aborted 120-day test, sterilization was accomplished by passing live steam through the system for a period of two to three hours. The product water collection tanks were sterilized separately in the autoclave. For the 30-day test, the water recovery side of the system was also sterilized in the autoclave.

After sterilization was complete, water was aseptically collected in sterile one-liter flasks and tested for sterility using Millipore filters as described below.

Microbiological Analysis

1. Urine Feed

Urine was obtained from the urine feed tank for the purposes of quantitation and identification of microorganisms present. Quantitation was performed by making 10-fold dilutions of the urine feed in sterile water blanks, pipetting 1.0 ml of the desired dilution into a petri dish, and adding melted Trypic Soy agar. All dilutions plated were done in duplicate and the counts averaged. Incubation was at 35°C for 48 hours, at which time colony counts were made. Urine was also inoculated onto blood agar, eosin-methylene blue agar and Sabouraud dextrose agar. Microorganisms isolated on these media were identified using standard techniques.

2. Product Water

At each sampling period, two liters of water were obtained by syphoning water out of the potable water storage tank into two one-liter sterile flasks. The water was then passed through 0.45μ millipore filters (1 liter water per filter). The filters were then placed on Tryptic Soy agar; one plate was incubated aerobically and the other anaerobically. An aerobiasis was obtained using the BBL Gas Pak system. All plates were incubated for 72 hours at 35°C and inspected for growth at 24 hours. When it was possible to obtain only one liter of water, only the aerobic plate was done.

3. Identification

Identification of isolated microorganisms was performed using standard techniques such as microscopic and colonial morphology, the use of differential and selective media, biochemical tests, and, when necessary, serological procedures.

4. Media

The medium used for quantitation was Trypic Soy agar. For isolation of gram positive and negative bacteria (from urine and brine samples), phenylethyl alcohol agar with 5.0 percent sheep blood added and eosin methylene blue were used, respectively. Blood agar (Trypic Soy agar base with 5.0 percent sheep blood) was used as a general medium. Mannitol salt agar was used for the isolation of coagulase positive Staphylococci. For the isolation of fungi, Sabouraud dextrose agar was used. Additional selective and/or differential media were used when the occasion demanded it.

RESULTS

Due to mechanical problems encountered during the test program, the study was divided into two parts; therefore, this part of the report discusses the aborted 120-day test and the 30-day test separately.

The Aborted 120-Day Test

Due to constant mechanical problems and shutdown of the system it was not possible to obtain consistent data. Table A-1 shows the results obtained from five samples of product water taken over a two-month period.

TABLE A-1

NUMBERS AND KINDS OF MICROORGANISMS ISOLATED FROM PRODUCT WATER

Sample No.	Date Taken	Total Aerobic Per Liter	Total[1] Anaerobic Per Liter	Organisms Isolated
1	4/27	16	0	Flavobacterium, Xanthomonas
2	4/28	1	5	Xanthomonas
3	5/6	0	0	
4	5/18	10	1	Flavobacterium, Xanthomonas, Pseudomonas sp.
5	6/10	TNTC[2]	10	ND[3]

1. No attempt at identification was made on any organism isolated on the anaerobic plates.
2. TNTC = too numerous to count.
3. ND = not done.

Water samples taken prior to the start of the program were sterile; the last such sample taken was two days prior to the actual start of the test. The data in Table A-1 show relatively low counts of bacteria in the product, with Flavobacterium and Xanthomonas being the predominant organisms isolated. No fungi were isolated in any of the five water samples tested.

Four samples of urine feed were obtained during this period of time. Total microbial counts were consistently low, showing less than 100 organisms per ml of urine feed. The last sample of urine feed was taken at the same time as product water sample number 5. The microbial counts in the urine feed were greater than 10^5 organisms per ml. The organisms isolated from the urine feed were those commonly expected in urine and consisted of the following: Enterobacter aerogenes, Enterobacter liquifaciens, Escherichia coli, Proteus mirabilis, P. vulgaris, P. rettegeri, Pseudomonas aeruginosa and Enterococci (Group D Streptococci). No isolations of Flavobacterium, Xanthomonas or species of Pseudomonas other than aeruginosa were made. Among the fungi, only Candida albicans was isolated.

Two brine samples were obtained, both samples containing approximately 30 percent solids. Total counts on both samples were greater than 10^6 organisms per ml brine. Identification of organisms isolated from the brine showed the first brine sample to contain only Enterococci; the second brine sample contained P. vulgaris, P. mirabilis, and P. rettgeri. No fungi were isolated.

The 30-Day Test

During this phase of testing, six samples of product water and one sample of brine concentrate were obtained. Results of the microbiological analysis of the product water are given in Table A-2.

TABLE A-2

NUMBERS AND KINDS OF ORGANISMS ISOLATED FROM PRODUCT WATER DURING THE 30-DAY TEST

Sample No.	Date Taken	Site	Total Aerobic Per Liter	Total[1] Anaerobic Per Liter	Organisms Isolated
1	10/23	Tank	28[4]	2[4]	Flavobacterium, Xanthomonas
2	10/30	Tank	0	0	
3	11/4	Tank	TNTC[2,4]	ND[3]	ND
4	11/15	Cyclic Accumulator	8[4]	ND	ND
5	11/15	Cyclic Accumulator	25[4]	ND	Flavobacterium, Pseudomonas sp.
6	11/19	Cyclic Accumulator	0	ND	

1. No attempt at identification was made on any organism isolated on the anaerobic plates.
2. TNTC = too numerous to count. Attempts to pull this sample of water through the filter were unsuccessful as only about 150 ml of water would pull through before the filter clogged. Thus, four filters were used for a total sample of approximately 600 ml. Each filter was TNTC. See text below.
3. ND = not done.
4. Presence of microorganisms was due to contamination on the sampling valve.

Product water sample number 3 (Table A-2), when taken, appeared somewhat turbid. Upon filtration, only about 150 ml of water pulled through the filter, at which time the filter clogged. Microscopic examination of a filter showed the filter to be clogged with cotton fibers and a gelatinous type of material. The presence of these contaminants in the product water cannot be explained; however, due to the large numbers of microorganisms present, it was felt that some individual inadvertently contaminated the holding tank. It was therefore decided to collect product water directly from the cyclic accumulator. Samples 4, 5, and 6 were all collected from the cyclic accumulator. As shown in Table A-2, samples 4 and 5 contained low numbers of bacteria subsequently identified as members of the genera Flavobacterium and Pseudomonas. Since it was possible

that the lines hooked up to the cyclic accumulator and the tip of the collection system might be contaminated, it was decided to first drain about 50 ml of water prior to collection of the water sample. This procedure yielded a sterile water sample (sample number 6).

After completion of the 30-day run, both the cyclic accumulator and the condenser were sampled directly for the presence of microorganisms. Water still remaining in the cyclic accumulator was sampled and found sterile. The condenser was taken apart and sampled with sterile prewetted cotton swabs. All such samples were found to be sterile when sterility tested in Thioglycollate medium.

One brine sample was obtained. The solids content was at 55 percent. No microorganisms were isolated.

CONCLUSIONS

Although microorganisms were isolated from the product water on numerous occasions, the organisms isolated (members of the genera Flavobacterium, Xanthomonas and Pseudomonas) indicate external contamination rather than an inability of the system to produce sterile water. Identification of bacteria isolated from the urine feed and brine did not reveal any of the above organisms isolated from the product water. Although such organisms may occasionally be found in urine and have, in rare instances, been implicated in urinary tract infections, their absence in the urine feed and brine concentrate and their continued isolation from the product water suggests contamination of the delivery system downstream of the reactor. These non-fermentative gram negative rods isolated from the product water are commonly found in water and soil and are frequently found in sink traps and rubber hoses attached to faucets and from a wide variety of sources in the human. Their presence in the product water was probably due to contamination of the stainless steel tubing used to siphon of the water, as well as the tip of the delivery system used to obtain the water sample. When water was first drained prior to obtaining a water sample, the water was found to be sterile.

The two instances where large numbers of organisms were found in the potable water supply (sample number 5, Table A-1; sample number 3, Table A-2) can be accounted for. In the first instance, the pyrolytic reactor had broken down and the system as a whole was malfunctioning, allowing microorganisms to gain entry to the delivery side of the system. In the second case, the finding of cotton fibers in the product water indicated some inadvertent mishandling of the potable water storage tank.

The contamination of the siphon tubing and delivery tip was probably due to constant manipulation to obtain water samples for chemical anslysis or to bleed off excess water. Greater care could have been taken to avoid contaminating these surfaces.

The culturing of the cyclic accumulator and the condenser after completion of the 30-day test showed no organisms to be present in either of these component parts, thus indicating a sterile water supply being produced by the vacuum distillation process.

Brine concentrate samples containing 30-percent solids were heavily contaminated with bacteria; however, the brine sample with a solids content of 55 percent was sterile, even after dilution. Bacteria do not grow well at low levels of water activity, a situation which would be true of both the 30 and 55 percent samples. In the latter, it is possible that the accumulation of toxic products exerted a bactericidal effect.